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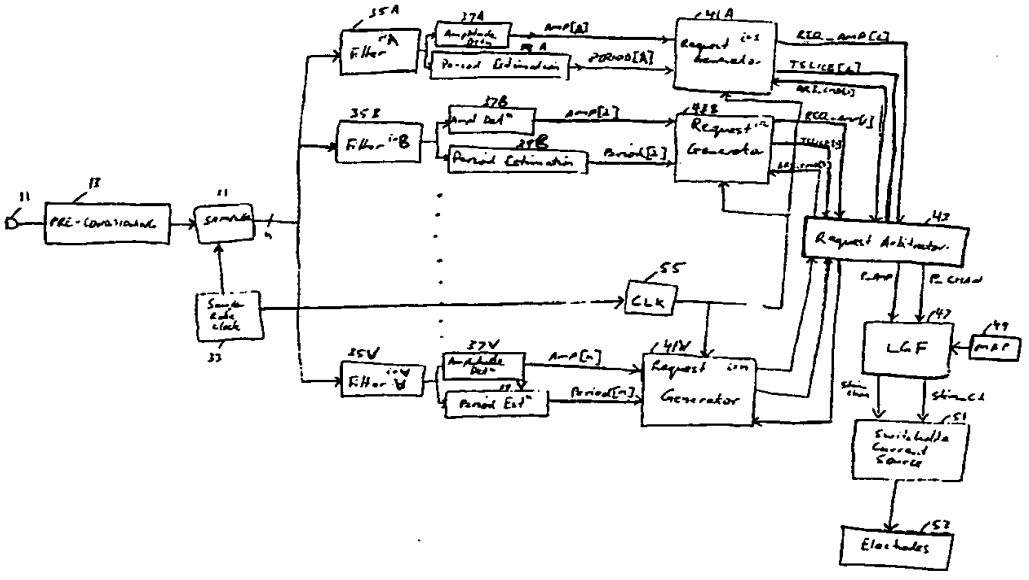

(57) Abstract: An improved processing approach is disclosed in order to allow for different rates of stimulation to be used for different electrodes in a multi-electrode cochlear implant. When the incoming signal is processed by filter array (35), each channel is processed to determine amplitude (37) and to estimate the period of the signal in that channel (39). The amplitude and period information is used to determine which electrode is stimulated, and the timing of that stimulation.

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MULTIRATE COCHLEAR STIMULATION STRATEGY AND APPARATUS

Technical Field

The present invention relates to cochlear implant prostheses and in particular to an apparatus and method for applying stimulation to the neural structures of a cochlea in order to improve a subject's pitch and speech perception.

Background Art

Cochlear implant systems are used to aid patients having a hearing deficiency. More particularly, these systems include a microphone receiving ambient sounds and converting the sounds into corresponding electrical signals, signal processing means for processing the electrical signals and generating cochlear stimulating signals and an electrode assembly for applying the cochlea stimulating signals to the cochlea of an implantee. In response to these electrical stimulations a perception of corresponding ambient sound is elicited in the implantee.

The inner ear of a normally hearing person includes hair cells which convert the displacement of the ear's basilar membrane in response to sound into nervous impulses. Different parts of the basilar membrane of the normal cochlea are displaced maximally by different frequencies of sound so that low frequency sounds maximally displace apical portions whereas higher frequency sounds cause displacement of more basal portions of the membrane. The nervous system is arranged so that a nervous impulse originating from a hair cell located adjacent an apical area of the membrane is perceived as a low frequency sound whereas a nervous impulse originating from a hair cell located adjacent a more basal position of the membrane is perceived as a higher frequency sound. This mapping of position to pitch is well known in the art as the tonotopic arrangement of the cochlea.

In a dysfunctional ear the hair cells may be damaged or absent so that no nervous impulses are generated. In such cases electrical stimulation impulses must be provided artificially to simulate the nervous activity of the hair cells in order to create a perception of sound.

With reference to figure 1, a typical cochlear implant is shown, which consists of an external component including a speech processor 1, and an

internal component including an implanted receiver and stimulator unit 6 and an intracochlear array 10. The external component further includes a microphone 2 which is shown integral with the speech processor 1. In this illustration the speech processor is arranged so that it can fit behind the ear with the microphone integral therewith. Alternative versions are also envisaged whereby the speech processor is worn on the body and separately attached to the microphone, and also where the speech processor and microphone are implanted in the patient. The present invention is applicable to all these alternatives.

In such cochlear implant devices, ambient sounds are detected by a microphone and a transduced signal is thereby generated, representative of the ambient sound. A processor unit then processes this transduced signal according to one of many strategies, (some of which will be explained further below) and based on this processing stimulation currents are applied between the electrodes of a coupled array. For example, in "monopolar" mode stimulation, stimulation currents may be caused to flow between an electrode of the electrode array 10 and an extracochlear electrode 115. Nervous discharges elicited in the basilar membrane 8 are conveyed to the central nervous system of the wearer by auditory nerve 9.

In the event that the stimulation current flows between an apical electrode such as electrode 111 and extracochlear electrode 115 then a lower pitched hearing sensation will be perceived by a wearer of the prosthesis than will be the case if stimulation current flows between basal electrode 107 and extracochlear electrode 115 because of the previously mentioned tonotopic arrangement of the cochlea. Further pitch information may be transmitted to the wearer corresponding to the rate at which stimulations are delivered.

Many possibilities exist as to the manner in which the signal processing means operates upon the electrical signals in order to produce stimulation signals. However it has been noted in the past that simultaneous stimulation of electrodes is not generally conducive to eliciting a perception of sound that is faithful to the actual acoustic signals being processed. This is because if electrodes are stimulated simultaneously, current paths between electrodes can interact, causing undesirable stimulation. Consequently most cochlear prosthesis stimulation strategies stimulate by means of only one electrode at a

time.

In the past designers of cochlear implant stimulation strategies have striven to optimise the intelligibility of spoken words as perceived by the wearer of a cochlear implant.

One of the earliest sound processing and cochlear stimulation strategies is described in US patent 4,532,930 to the present applicant. In that patent there is taught the use of a filter (F0) dedicated to extracting the voice pitch of a speech signal. The periodicity of the voice pitch is used to set the stimulation periodicity for two or three electrodes. A second, and possibly third, channel is analysed to determine periodicity and amplitude in a selected frequency band.

The periodicity extracted from the second filter, and possibly third filter, is used to select which electrode is stimulated for the second and third channels while the periodicity of stimulation of the channel is determined by the periodicity of the output signal from the F0 filter.

Another stimulation arrangement is described in US 4,207,441. In that system there are n electrodes each coupled to one of n filters. Each electrode is stimulated once per analysis period, with an intensity corresponding to the amplitude of the corresponding filter channel. The analysis period of this system is predetermined and hence is not related to the signal on the filter outputs.

More recently in EP 0 745 363 there is described a stimulation system which takes into account the temporal behaviour of the cochlea. In an embodiment of the invention therein described a wavelet transformation is used to extract the temporal information with a view to using this information to determine the sequence of stimulation of the electrodes. The purpose of the invention is to improve the temporal resolution in response to a rapidly changing audio spectrum.

A problem that has been faced by users of cochlear implants featuring prior art stimulation schemes is that while intelligibility of spoken words is often good the user's pitch perception, and in particular perception of music, is poor. Accordingly, it is an object of the present invention to provide an apparatus and method for use in a multi-channel cochlear implant which will improve a user's perception of pitch.

Summary of the Invention

Broadly, the present invention seeks to use information about the periodicity of the signal in each filter channel as a factor in determining the rate of stimulation applied to a tonotopically placed electrode which corresponds to the relevant channel. This allows for an improved perception of pitch by the implant user. As a result, the rate of stimulation which occurs in practice for each electrode will be related to the periodicity of the signal in the filter channel corresponding to that electrode.

According to one aspect of the present invention there is provided a cochlear implant prosthesis of the type having a transducer for converting an acoustic signal to an electrical signal, a plurality of bandpass filtering means responsive to said electrical signal and operatively producing a plurality of bandpass filtered signals, signal processing means responsive to said plurality of bandpass filtered signals and operatively generating stimulation commands, electrode driving means responsive to said stimulation commands and an electrode array coupled to said electrode driving means for operatively delivering to a user of said cochlear implant prosthesis stimulations in accordance with said stimulation commands, said signal processing means including:

a) period estimation means, responsive to said filtered signals and operatively generating periodicity signals indicative of the periodicity of each of at least a number of said plurality of filtered signals;

b) amplitude estimation means responsive to said filtered signals and operatively generating magnitude signals indicative of the magnitude of each of said plurality of filtered signals;

c) selection means responsive to said magnitude signals arranged to select only one filtered signal of said plurality of filtered signals in each stimulation period, said selection means generating said stimulation commands including a command to stimulate by means of an electrode operatively tonotopically best corresponding to said one filtered signal, said command to stimulate further specifying a time for stimulation to occur dependent on a corresponding one of said periodicity signals.

According to another aspect, the present invention provides a processing device for a cochlear implant prosthesis, said prosthesis being of the type

including electrode driving means responsive to stimulation commands and an electrode array coupled to said electrode driving means for operatively delivering to a user of said cochlear implant prosthesis stimulations in accordance with said stimulation commands,

said processing device being responsive to a transducer for converting an acoustic signal to an electrical signal and including a plurality of bandpass filtering means responsive to said electrical signal and operatively producing a plurality of bandpass filtered signals, signal processing means responsive to said plurality of bandpass filtered signals and operatively generating stimulation commands, said signal processing means including:

a) period estimation means, responsive to said filtered signals and operatively generating periodicity signals indicative of the periodicity of each of at least a number of said plurality of filtered signals;

b) amplitude estimation means responsive to said bandpass filters operatively generating magnitude signals indicative of the magnitude of each of said plurality of filtered signals;

c) selection means responsive to said magnitude signals arranged to select only one filtered signal of said plurality of filtered signals in each stimulation period, said selection means generating said stimulation commands including a command to stimulate by means of an electrode operatively tonotopically best corresponding to said filtered signal, said command to stimulate further specifying a time for stimulation to occur dependent on a corresponding one of said periodicity signals.

According to a further aspect of the present invention there is provided a method of operating a cochlear implant prosthesis of the type including a plurality of bandpass filters each having a characteristic centre frequency, said filters generating a corresponding plurality of filtered signals, said prosthesis further including stimulation delivery means coupled to an electrode array, said method including the steps of :

a) in each of a number of time intervals, determining the amplitude for each of said plurality of filtered signals and a periodicity value for at least some of said plurality of filtered signals;

b) selecting only one of said signals as a basis for stimulation in each stimulation period; and

c) applying a stimulation current by means of an electrode of said electrode array tonotopically closest to the centre frequency of the bandpass filter producing the signal determined in step b), said stimulation current being applied during a time interval determined from the periodicity value of the signal determined in step b).

Brief Description of the Drawings

Figure 1 depicts a typical cochlear implant device.

Figure 1A depicts a block diagram of the functional elements of a cochlear implant according to the present invention.

Figure 2 depicts a dedicated hardware version of a cochlear implant prosthesis according to the present invention.

Figure 3A is a graph of a possible output of an amplitude estimator module of Figure 2.

Figure 3B is a graph of a possible output of a period estimator module of Figure 2 of the same channel as the amplitude estimator of Figure 3A.

Figure 3C is a graph of stimulation currents generated via an electrode in accordance with the amplitude and period estimates of Figures 3A and 3B.

Figure 3D is a graph of stimulation currents generated via a further electrode having a stimulation current occurring simultaneously with a stimulation current in the graph of Figure 3C.

Figure 3E is a graph of a single stimulation current.

Figure 4 is a flowchart of procedural steps used in implementing the present invention by means of software on an apparatus of the type depicted in Figure 1A.

Figure 5 is a flowchart of procedural sub-steps involved in one of the boxes appearing in Figure 3.

Detailed Description

The present invention will be described with reference to a specific implementation. However, it will be appreciated that the present invention can be implemented in various ways, with suitable modifications to suit the cochlear implant system in question.

With reference to Figure 1A, there is depicted a simplified digital hardware implementation of a cochlear prosthesis according to the present invention. Sound waves are transduced by microphone 11 and the electrical signal so produced is processed by a signal conditioning module 13. Signal conditioning module 13 includes standard circuits for pre-amplifying and low pass filtering the signal prior to its processing by analog to digital converter 15. Analog to digital converter 15 produces a 16 bit digital signal which is conveyed to microprocessor 17. Microprocessor 17 operates according to a program stored in EPROM 19. Microprocessor 17, in accordance with its program operates upon the digital signal in order to generate a sequence of stimulation commands which are delivered to a switchable current source module 23. The commands delivered to the switchable current source module 23 specify the amplitude of the current that is to flow from one or more electrode to one or more other electrodes, the timing of the stimulation current, and the mode of the stimulation.

The term 'mode' here refers to the selection of electrodes between which a stimulation current is to flow. Well known stimulation modes include bipolar, monopolar and common ground. Upon receiving commands specifying the parameters of the stimulation to be applied, switchable current source module 23 connects various electrodes of electrode array 21 to an internal controllable current source in order to generate the appropriate stimulation. The construction of a switchable current source is well known in the art and may be found in the applicant's US Pat No. 4,532,930.

Figure 2 depicts a dedicated hardware implementation of the invention for purposes of explanation. While Figure 2 illustrates the invention as if individual tasks performed by microprocessor 17 were embodied in dedicated hardware, it remains the case that the invention is most readily practised according to the arrangement of Figure 1A. The invention will however be explained with reference to Figure 2 in order to most clearly impart an understanding of its operation to the reader.

Referring to Figured 2 it will be noted that the analog signal from pre-conditioning module 13 is first sampled at 16 kHz by sampler 31 thereby producing a sampled signal. The sampled signal is split 22 ways, each of the split signals providing an input to digital filters 35A-35V which filter the signal into

quarter octave frequency bands. It will be appreciated that the numbers of ways the signal is split, and the sampling rate, are matters of design choice appropriate to the system in which the present invention is implemented.

Digital filters 35A-35V are bandpass and logarithmically spaced with the base frequency being typically at 150 Hz. Each filter is of a 6th order Chebychev Type I bandpass type implemented in three second order sections. The quarter octave frequency bands are as shown below:

Filter Band	Lower Frequency Boundary (Hz)	Upper Frequency Boundary (Hz)
A	150.00	178.38
B	178.38	212.13
C	212.13	252.27
D	252.27	300.00
E	300.00	356.76
F	356.76	424.26
G	424.26	504.54
H	504.54	600.00
I	600.00	713.52
J	713.52	848.53
K	848.53	1009.10
L	1009.10	1200.00
M	1200.00	1427.00
N	1427.00	1697.10
O	1697.10	2018.20
P	2018.20	2400.00
Q	2400.00	2854.10
R	2854.10	3394.10
S	3394.10	4036.30
T	4036.30	4800.00
U	4800.00	5708.20
V	5708.20	6788.20

The bandpass filtered signal from each of the digital filters, for example 35A, is connected to an amplitude detection module 37A and a period estimation module 39A. The output AMP[A] of amplitude detection module 37A is a digital signal representing an estimation of the amplitude of the sampled signal from filter 35A. The construction of module 37A is straightforward, well understood by those skilled in the art, and will not be explained in detail other than to say that it could be based on a series of comparators.

Period estimation module 39A counts sampling periods between positive zero crossings of the signal from filter 35A. The output signal PERIOD[A] is scaled so that it is expressed in units of "timeslices".

One "timeslice" is the time taken to deliver one stimulation pulse by means of an electrode. With reference to Figure 3E an example of a stimulation current pulse waveform comprises a first 'phase' 103 being a square wave of predetermined amplitude, an interphase gap 105 and a second phase 107 being

a current square wave of the same magnitude and duration as the first phase but flowing in the opposite direction between an intra-cochlear electrode and (in mono-polar mode) an extra-cochlear electrode. Time periods 109 and 111 are present in which the system generating the stimulations has time to perform any necessary operations in order to configure for the next stimulation. The overall time taken to set-up, deliver and recover from application of a stimulation is one timeslice, in the present example a timeslice is of approximately 69 microseconds duration.

In the present implementation the preferred maximum stimulation rate is 8kHz whereas the preferred sampling rate is 16kHz. Accordingly PERIOD[A] is the number of samples occurring between positive-going zero crossings divided by two and rounded. The PERIOD[A] signal is updated at the end of each period.

The AMP[A],...,AMP[V] and PERIOD[A],...,PERIOD[V] signals contain magnitude and period information concerning the ambient sound picked up by microphone 11 for each of the frequency bands monitored by bandpass filters 35. It is possible to simply stimulate via each corresponding electrode e[i] with a current intensity corresponding to AMP[i] at a time PERIOD[i] into the future in order to convey the information generated by amplitude detectors 37 and period estimators 39 to a wearer of the cochlear prosthesis. For example, with reference to Figures 3A, 3B and 3C a stimulation sequence via electrode e[A] is shown corresponding to amplitude and period values generated by amplitude detection module 37A and period estimation module 39A as shown plotted in Figures 3A and 3B. Period[A] is equal to P1 at time t=0 and Amp[A] is equal to a1. Accordingly at a time t=P1 a stimulation current is delivered via electrode e[A] of electrical amplitude I(a1) where I() is a loudness growth function which maps amplitude into the dynamic range of the wearer of the prosthesis.

The period P2 and amplitude a2 values are then obtained and a further stimulation is delivered at time t=P1+P2 of amplitude I(a2). This process is repeated continuously to produce the stimulation sequence of biphasic current pulses shown in the graph of Figure 3C. As previously mentioned, such a process could be simultaneously performed independently on all channels of the implant, (a "channel" as used here refers to a stimulation electrode, its

corresponding filter and period and amplitude estimation modules).

In the system thus far described the period estimation module 39A produces a period estimate which is simply the time delay between the last two positive-going zero crossings. While this system works well, any noise on the individual period estimates will degrade the performance of the system. To prevent this, it is desirable to calculate a smoothed period estimate.

The individual period estimates constitute a number sequence which is amenable to any of the methods of smoothing known to the art of digital signal processing. The smoothing may, for example, be implemented as a simple FIR or recursive digital filter - preferably a low-pass filter. Alternatively a rank-order filter, such as a median filter may be used. A rank-order filter has the advantage that it will completely remove any single data errors from the number sequence. A smoothed period estimate is thus produced by applying the sequence of period estimates to a digital filter, and taking the output of that filter. The smoothed period estimate is then utilised by taking the most recent output from the filter and using it in place of the (unsmoothed) period estimate.

With reference to Figure 3D there is shown a stimulation sequence via electrode e[B]. It will be noted that stimulation pulse 102 occurs at exactly the same time as stimulation pulse I(a2) of Figure 3C. Such coincidences occur more and more frequently depending on the number of channels used.

There are at least two problems associated with the above stimulation strategy by which stimulations may be delivered by two or more electrodes simultaneously. Firstly, as discussed above, it is well known that simultaneous, or very near simultaneous, stimulation produces a deterioration in the quality of the sound perceived by the user, due to the interaction of simultaneous current paths between the electrodes.

Consequently the application of stimulations on a number of channels simultaneously is undesirable. A further problem is that simultaneous stimulation requires very substantial processing power and so is not possible in the majority of cochlear implants presently available.

In light of the above problems the inventors have incorporated a preferred refinement for determining which information signals, coming from amplitude

detectors 37 and period estimation modules 39 are most appropriate for acting upon in order to produce a high quality percept in a user. According to the invention, for any stimulation period i.e. "timeslice" t0 the signals AMP[A,t0],...,AMP[V,t0] are ordered according to magnitude and a stimulation current is generated by means of the electrode which corresponds to the signal AMP[A,t0],...,AMP[V,t0] having the greatest magnitude. (It should be noted that, when implanted, electrodes e[A],...,e[V] are tonotopically mapped to filters fA,...,fV so that electrode e[A] is most apically placed whereas electrode e[v] is most basally placed.) For example, if it is found that AMP[F,t0] has the greatest magnitude at a given timeslice then electrode e[F] is used to deliver the monopolar stimulation in the next timeslice t1.

A further variation to this scheme is that a number of the next largest magnitude signals are also determined in the same timeslot, for example AMP[G,t0] > AMP[B,t0] > AMP[K,t0] might be determined to have the magnitudes next greatest to AMP[F,t0]. In that case those values are assigned to AMP[G,t1], AMP[B,t1] and AMP[K,t1] respectively. During the next timeslice, t1, the procedure is repeated and it may be that AMP[G,t1] is selected as having the greatest magnitude so that electrode e[G] is selected for delivering a stimulation pulse of amplitude corresponding to AMP[G,t1]=AMP[G,t0]. By using this scheme it is possible that signals having a large magnitude, though not the greatest, are presented to the user after a short time delay. The inventors have found that most acoustic power is centred around the lower frequency bands which have longer periods associated with them whereas the higher frequency bands generally have less power associated with them as well as being of shorter period. Accordingly, it is predominantly higher frequency sounds which are delayed rather than lower frequency sounds.

A further refinement is that rather than calculate period estimates in respect of the outputs from filters centred at higher frequencies, for example for filters FI,...,FV period estimators 39I,...,39V simply generate a constant signal, or periodicity value, indicating a period of 1.25ms i.e. a periodicity value towards the highest stimulation rate that the device is capable of supporting.

While the preceding description covers a system utilising period estimators on some or all of the bandpass filtered signals, it is possible to implement the system more simply. A stimulus could be requested each time a positive zero-crossing is detected on a filter output. Once per timeslice each channel is interrogated to see if it has a stimulation request pending. If there are no requests pending, then no action is required. If there is exactly one request pending, then a stimulus is generated corresponding to that request.

If more than one request is pending, then the following actions are taken. The requests are sorted according to the amplitudes of the corresponding bandpass filtered signals. A stimulus is generated corresponding to the bandpass filtered signal with the largest amplitude. The next N largest (preferably 5 largest) amplitude requests are delayed by one timeslice. Any remaining requests are cancelled.

This system is simpler to implement than that previously described. It has two main disadvantages, however. The previously described system utilising period estimates acts to limit the stimulation rate on higher frequency channels. This is directly beneficial in that excessive stimulation with little information content is avoided. More importantly, in the case of relatively large amplitude high frequency signals, the lower frequency signals will be completely lost in the simpler system. The rate-limiting effect of the period-estimation system will mean that the low-frequency signal will always get through.

The request generators 41-A,..,41-V and request arbitrator 43 operate to determine which electrode will be stimulated from the AMP[A],...,AMP[V] and PERIOD[A],...,PERIOD[V] signals. The operation of the request generators and the request arbitrator, in order to implement the aforedescribed scheme, will now be explained with exemplary reference to request generator 41A.

The AMP[A] and PERIOD[A] signals are inputs to request generator module 41A. Another input to the request generator is the CLK signal which corresponds to the present timeslice. The CLK signal is modulus 256 to avoid overflow problems. The last input to request generator 41A is a command signal ARB_CMD[A] from request arbitrator 43.

The outputs from request generator 41A are TSLICE[A] and REQ_AMP[A].

The TSLICE[A] represents the time at which it is proposed by generator 41A that a stimulation be delivered having an amplitude value represented by REQ_AMP[A].

The relationship between TSLICE[A] and PERIOD[A] and REQ_AMP[A] and AMP[A] is determined by the value of the ARB_CMD[A] signal. The ARB_CMD[A] signal can take one of three values REQUEST, DELAY, DISCARD. When ARB_CMD[A] takes the value :

REQUEST

then REQ_AMP[A] := AMP[A]; TSLICE[A] :=CLK+PERIOD[A]

DELAY

then TSLICE[A] := TSLICE[A] + 1

DISCARD

take no action.

The principle behind these rules is that in the event that request arbitrator 43, whose operation will shortly be described, determines that a stimulation pulse should be applied corresponding to the output from filter 35A then by sending an ARB_CMD[A] signal having the value REQUEST to request generator 41A the amplitude and timing of the stimulation pulse is made available at the next timeslice. Alternatively, if ARB_CMD[A] takes the value DELAY then the corresponding TSLICE[A] variable is incremented. Construction of the request generator, in order to implement the above rules is readily accomplished according to established synchronous digital design techniques.

Request arbitrator module 43 takes as its input the signals TSLICE[A],.., TSLICE[V] from each of the request generators 41A-41V, REQ_AMP[A],.., REQ_AMP[V] and the CLK signal. Arbitrator module 43 generates a signal P_CHAN which identifies which of electrodes e[A],..,e[V] of the electrode array is to be used to apply a stimulation.

The arbitrator module also generates a signal P_AMP which takes a value REQ_AMP[A],..,REQ_AMP[V] which is used, after scaling as will subsequently be described, to determine the amplitude of the signal to be used when applying stimulation. Request arbitrator module 43 operates according to the following rules:

1. Find all TSLICE[i] with a value equal to CLK.

2. Find N channels of those determined in Step 1 which have the largest value of REQ_AMP[j]. The channel with the largest value of REQ_AMP[j] and TSLICE[j] as determined in step 1 is found and P_CHAN set to j and P_AMP set to REQ_AMP[j]. So that a stimulation is directed via electrode e[j] with amplitude scaled from the value P_AMP=REQ_AMP[j]. This is accomplished by setting the ARB_CMD[j] signal to REQUEST.

3. The channels having the next N-1 largest amplitude values REQ_AMP[] are delayed by one timeslice for consideration during set up for the next stimulation. This is achieved by sending an ARB_CMD[] signal to the corresponding N-1 request generators to DELAY.

4. The remaining channels, which were selected in step 1 but not in step 2 are discarded. This is achieved by sending the corresponding request generators an ARB_CMD[] signal of value DISCARD.

5. If any of the request generators is sending a specific "no pulse request" then the corresponding ARB_CMD[] signals are set to REQUEST.

Once the P_CHAN and P_AMP values have been determined they are passed to Loudness growth function module 47. The growth function module takes into account the predetermined comfort and threshold levels of the user of the cochlear prosthesis in order to map the P_AMP values into the listeners dynamic range. Such mapping is known in the prior art and the reader is referred to US Patent No. 4,532,930 to the same applicant for further details.

The invention is most conveniently practised, in accordance with the embodiment of Figure 1, by programming a SPrint speech processor, available from Cochlear Limited of 14 Mars Road, Lane Cove, NSW 2066, Australia, in order to perform the operations described in relation to Figure 2. The SPrint speech processor is used in conjunction with a CI24M cochlear implant receiver-stimulator from the same vendor.

With reference to Figure 4 there is depicted a block diagram of the overall operational procedure for implementing the present invention in software. At block 201, for each sample period, the sound signal is filtered into the required number of channels. At block 202, the signal in each channel is analysed to determine its

amplitude, and the period of the signal. The latter may be performed by determining the time between successive zero crossings, as described above. Based upon the values for the amplitude and period for each channel, block 203 selects which channel signal is to be used as the basis for stimulation, and hence the electrode to be stimulated. Loudness mapping block 204 performs the function of mapping the desired amplitude stimulus within the dynamic range for the selected electrode. The latter step is well known to those skilled in the art.

Figure 5 further details the operational steps performed in box 203 of Figure 4. At initialisation, in block 210, the stimulus selector updates all inputs. The inputs are the values for amplitude and period as described previously. At block 211, each input channel is checked to determine if a stimulation is being requested for the next period, based upon the period value, and all such channels are sorted according to amplitude. At block 212, all channels but the largest amplitude channel are delayed to a later stimulation period. In block 214, the largest amplitude channel is selected as the basis for stimulation, and the inputs for that channel are updated to reflect that a stimulus will be delivered that period. Block 213 completes the process by discarding the remaining channels by updating their inputs, and returning to the process of block 210 for the next period, time j.

While the invention has been described with reference to preferred embodiments, it is to be understood that these are merely illustrative of the application of principles of the invention. Accordingly, the embodiments described in particular should be considered exemplary, not limiting, with respect to the following claims.

Claims

1. A cochlear implant prosthesis of the type having a transducer for converting an acoustic signal to an electrical signal, a plurality of bandpass filtering means responsive to said electrical signal and operatively producing a plurality of bandpass filtered signals, signal processing means responsive to said plurality of bandpass filtered signals and operatively generating stimulation commands, electrode driving means responsive to said stimulation commands and an electrode array coupled to said electrode driving means for operatively delivering to a user of said cochlear implant prosthesis stimulations in accordance with said stimulation commands, said signal processing means including:

a) period estimation means, responsive to said filtered signals and operatively generating periodicity signals indicative of the periodicity of each of at least a number of said plurality of filtered signals;

b) amplitude estimation means responsive to said filtered signals and operatively generating magnitude signals indicative of the magnitude of each of said plurality of filtered signals;

c) selection means responsive to said magnitude signals arranged to select only one filtered signal of said plurality of filtered signals in each stimulation period, said selection means generating said stimulation commands including a command to stimulate by means of an electrode operatively best corresponding to said one filtered signal, said command to stimulate further specifying a time for stimulation to occur dependent on a corresponding one of said periodicity signals.

2. A cochlear implant prosthesis according to claim 1, wherein said period estimation means operatively determines a value for the time between successive zero crossings by the filtered signal, and responsive to this value generates said periodicity signal.

3. A cochlear implant according to claim 2, wherein said period estimation means is further responsive to previous values of said time between successive zero crossings, so that a smoothed period estimate value is generated, and responsive to this value said period estimation means generates said periodicity signal.

4. A cochlear implant according to claim 3, wherein said periodicity signal is scaled to an integral multiple of the time taken to deliver one stimulation pulse.

5. A cochlear implant according to claim 1, wherein said selection means is responsive to the amplitude and selects said one filtered signal on the basis that said signal has the greatest amplitude.

6. A cochlear implant according to claim 1, wherein the rates of stimulation operatively delivered to each electrode differ from each other in response to said periodicity signals.

7. A processing device for a cochlear implant prosthesis, said prosthesis being of the type including electrode driving means responsive to stimulation commands and an electrode array coupled to said electrode driving means for operatively delivering to a user of said cochlear implant prosthesis stimulations in accordance with said stimulation commands,

said processing device being responsive to a transducer for converting an acoustic signal to an electrical signal and including a plurality of bandpass filtering means responsive to said electrical signal and operatively producing a plurality of bandpass filtered signals, signal processing means responsive to said plurality of bandpass filtered signals and operatively generating stimulation commands, said signal processing means including:

a) period estimation means, responsive to said filtered signals and operatively generating periodicity signals indicative of the periodicity of each of at least a number of said plurality of filtered signals;

b) amplitude estimation means responsive to said bandpass filters operatively generating magnitude signals indicative of the magnitude of each of said plurality of filtered signals;

c) selection means responsive to said magnitude signals arranged to select only one filtered signal of said plurality of filtered signals in each stimulation period, said selection means generating said stimulation commands including a command to stimulate by means of an electrode operatively best corresponding to said filtered signal, said command to stimulate further specifying a time for stimulation to occur dependent on a corresponding one of said periodicity signals.

8. A processing device according to claim 7, wherein said period estimation means operatively determines a value for the time between successive zero crossings by said filtered signal, and responsive to this value generates said periodicity signal.

9. A processing device according to claim 8, wherein said period estimation means is further responsive to previous values of said time between successive zero crossings, so that a smoothed period estimate value is generated, and responsive to this value said period estimation means generates said periodicity signal.

10. A processing device according to claim 9, wherein said periodicity signal is scaled to an integral multiple of the time taken to deliver one stimulation pulse.

11. A processing device according to claim 7, wherein said selection means is responsive to the amplitude and selects said one filtered signal on the basis that said signal has the greatest amplitude.

12. A processing device according to claim 7, wherein the stimulation commands are such that the rates of stimulation operatively delivered to each electrode differ from each other in response to said periodicity signals.

13. A method of operating a cochlear implant prosthesis of the type including a plurality of bandpass filters each having a characteristic centre frequency, said filters generating a corresponding plurality of filtered signals, said prosthesis further including stimulation delivery means coupled to an electrode array, said method including the steps of :

a) in each of a number of time intervals, determining the amplitude for each of said plurality of filtered signals and a periodicity value for at least some of said plurality of filtered signals;

b) selecting only one of said signals as a basis for stimulation in each stimulation period; and

c) applying a stimulation current by means of an electrode of said electrode array tonotopically closest to the centre frequency of the bandpass filter producing the signal determined in step b), said stimulation current being applied during a time interval determined from the periodicity value of the signal determined in step b).

14. A method according to claim 13, wherein said periodicity value is determined by acquiring a period value for the time between successive zero crossings by the filtered signal, and responsive to the period value generating said periodicity signal.

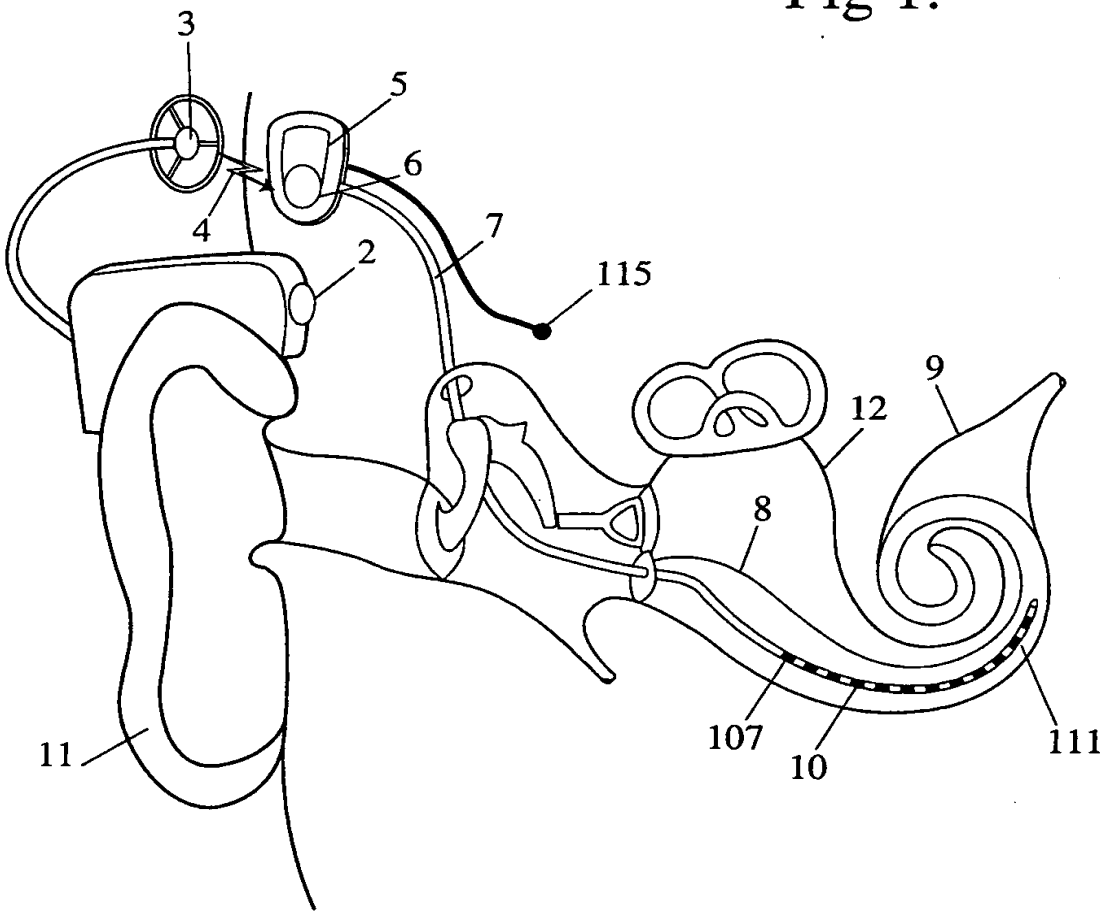
15. A method according to claim 14, wherein said periodicity value is determined using a smoothed period value, said smoothed value being determined in response to current and previous values of said period value, and responsive to said smoothed period value said periodicity signal is generated.

16. A method according to claim 15, wherein said periodicity value is determined for all of said filtered signals.

17. A method according to claim 16, wherein step (b) includes determining which of said plurality of signals has the greatest amplitude.

18. A method according to claim 13, wherein the rates of stimulation operatively delivered to each electrode differ from each other in response to said periodicity signals.

Fig 1.



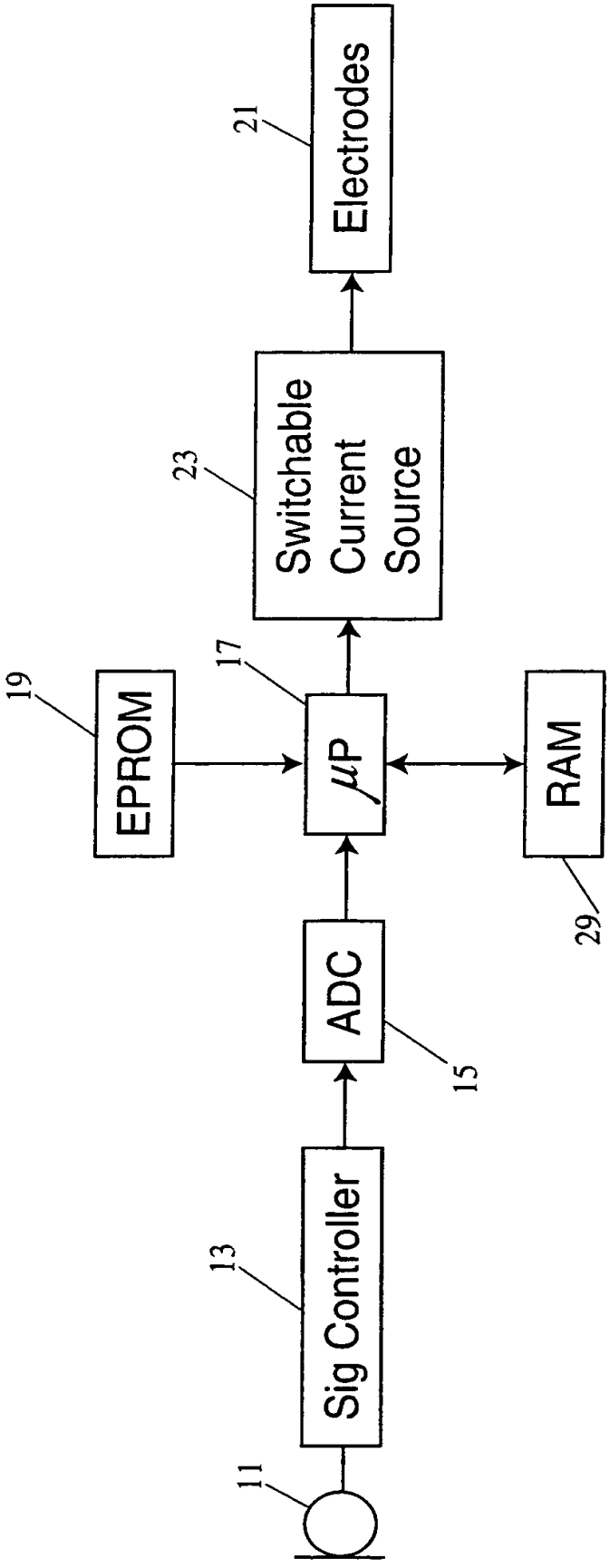

Electrodes
21
Switchable Current Source
23
EPROM
19
17
μP
RAM
29
ADC
15
Sig Controller
13
11

Fig 1a.

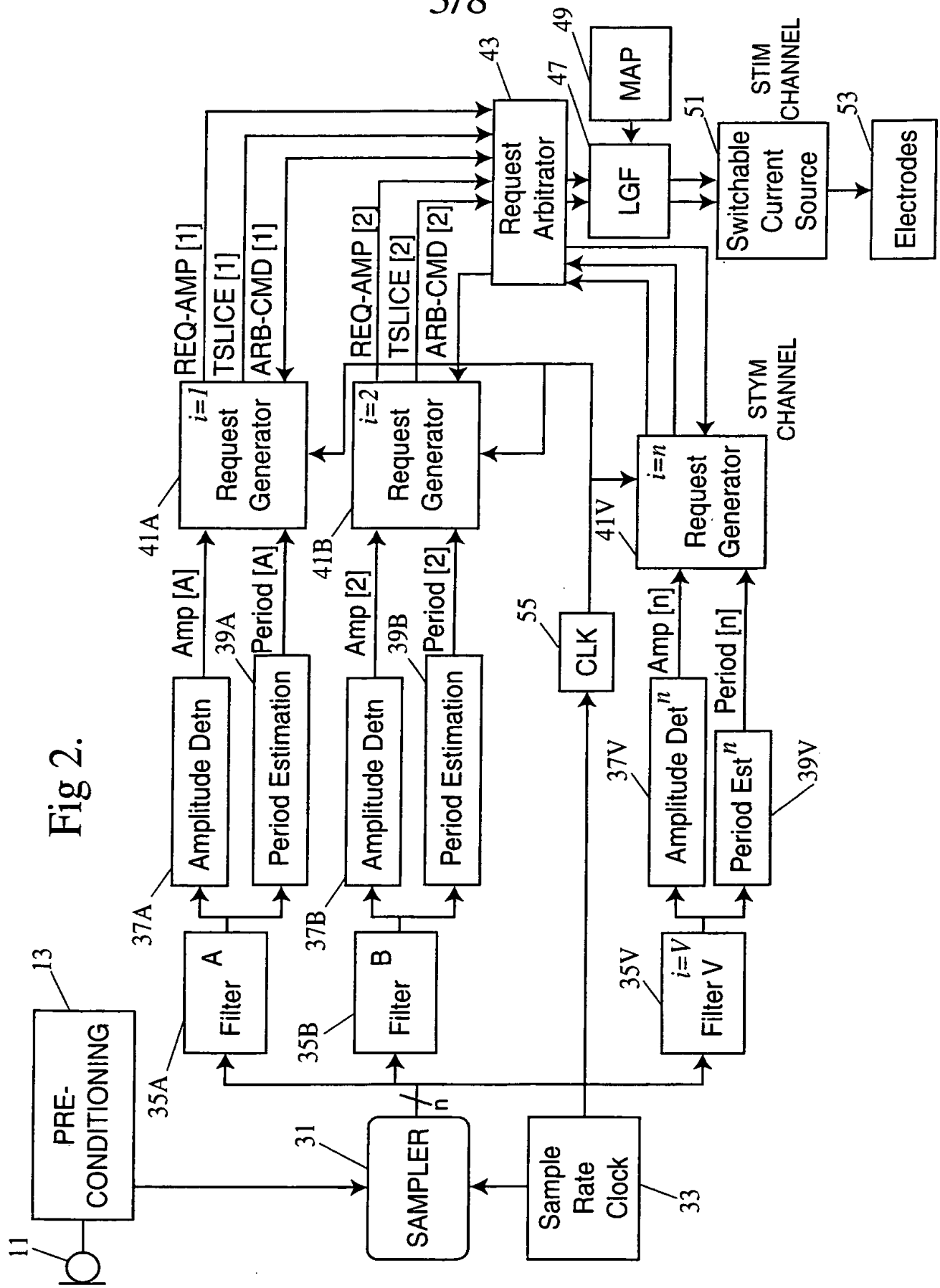

11
PRE-CONDITIONING
13
SAMPLER
31
n
Sample Rate Clock
33
A Filter
35A
B Filter
35B
i=V Filter V
35V
Amplitude Detn
37A
Amplitude Detn
37B
Amplitude Det^n
37V
Period Estimation
39A
Period Estimation
39B
Period Est^n
39V
Amp [A]
Period [A]
Amp [2]
Period [2]
Amp [n]
Period [n]
CLK
55
i=1 Request Generator
41A
i=2 Request Generator
41B
i=n Request Generator
41V
REQ-AMP [1]
TSLICE [1]
ARB-CMD [1]
REQ-AMP [2]
TSLICE [2]
ARB-CMD [2]
STYM CHANNEL
Request Arbitrator
43
MAP
49
LGF
47
Switchable Current Source
51
STIM CHANNEL
Electrodes
53

Fig 2.

Fig 3A.

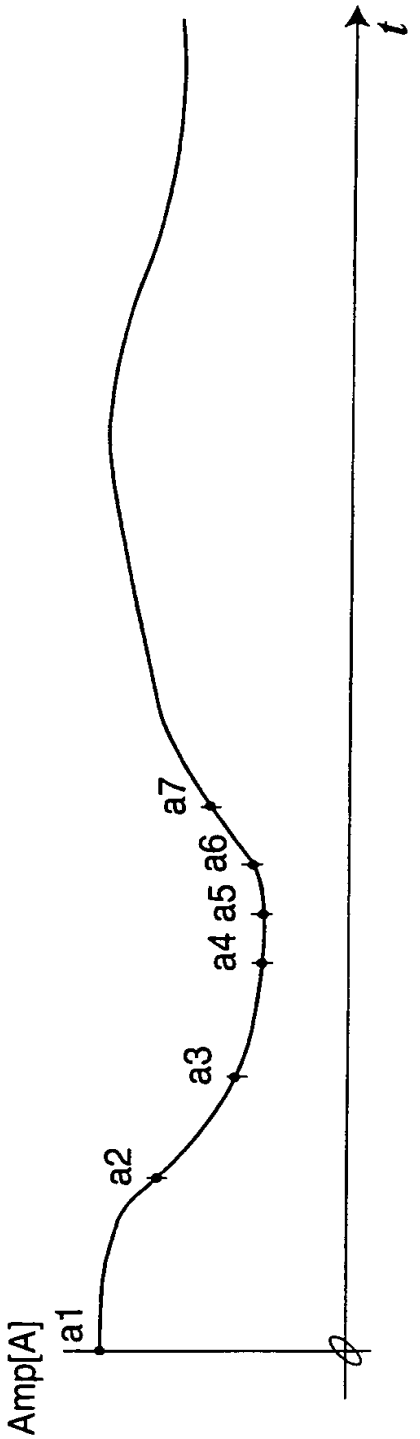
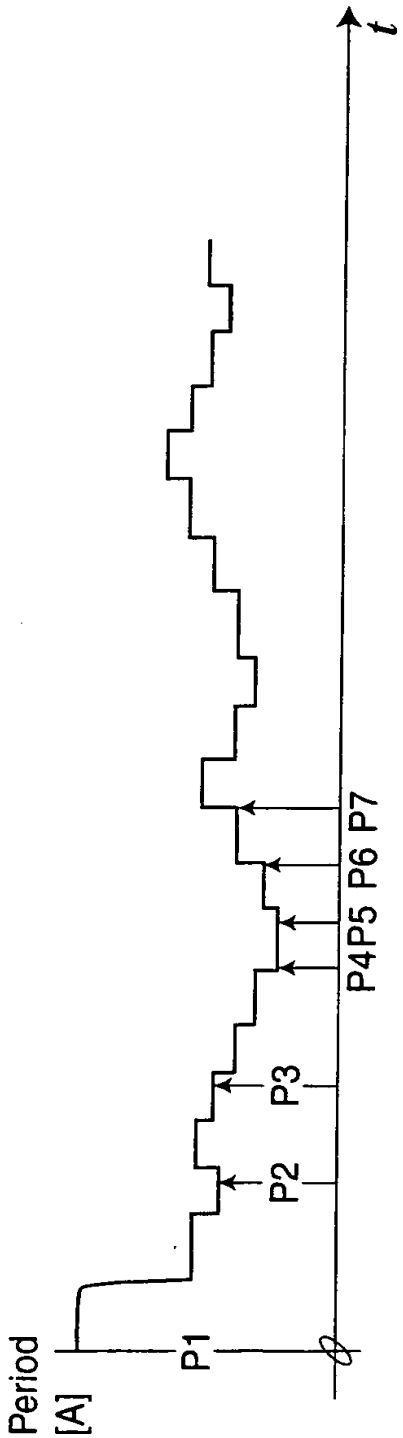


Fig 3B.



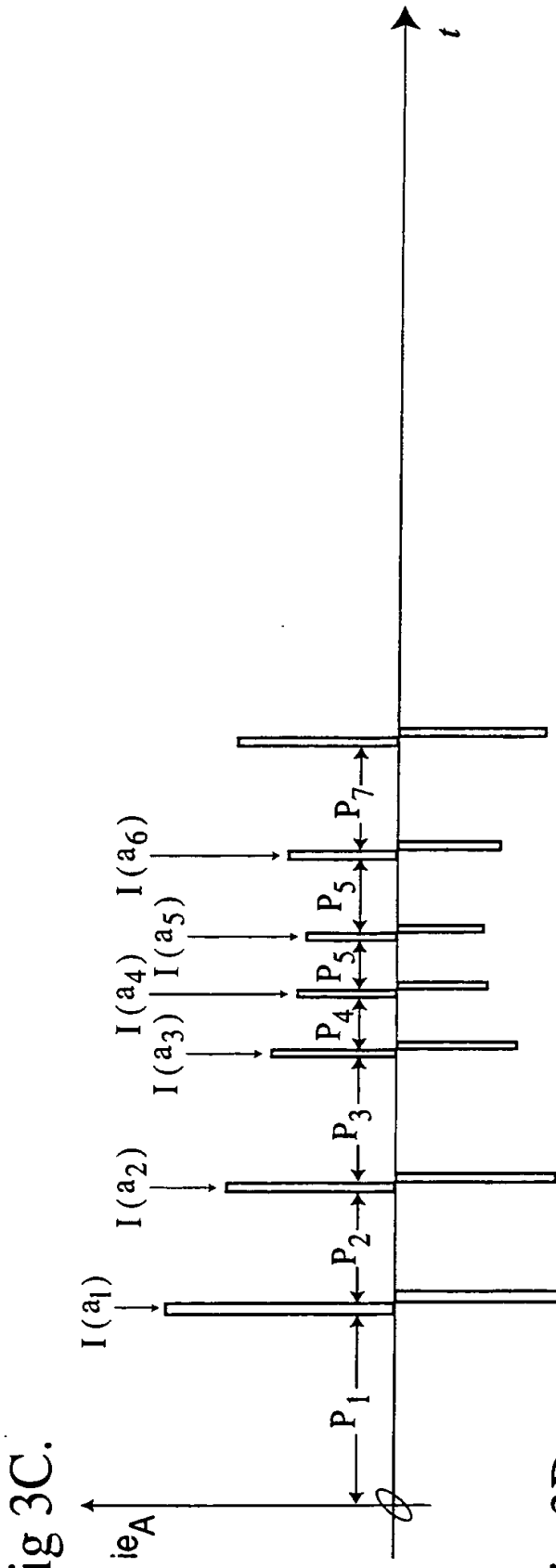

t
P_7
$I(a_6)$
P_5
$I(a_5)$
P_5
$I(a_4)$
P_4
$I(a_3)$
P_3
$I(a_2)$
P_2
$I(a_1)$
P_1
ie_A

Fig 3C.

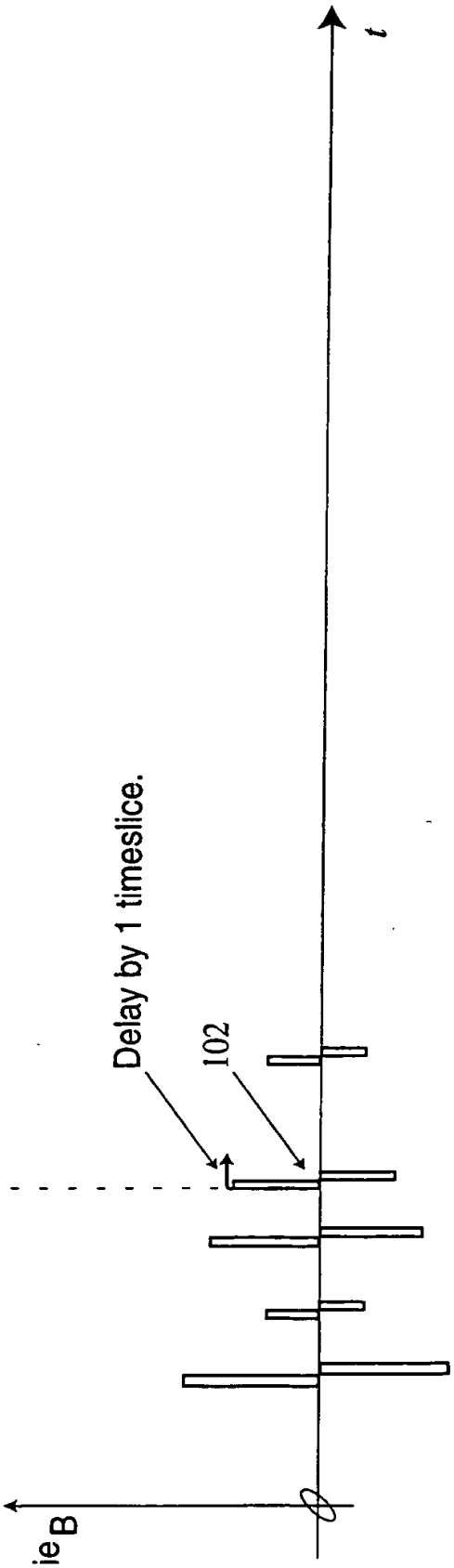

t
Delay by 1 timeslice.
102
ie_B

Fig 3D.

Fig 3E.

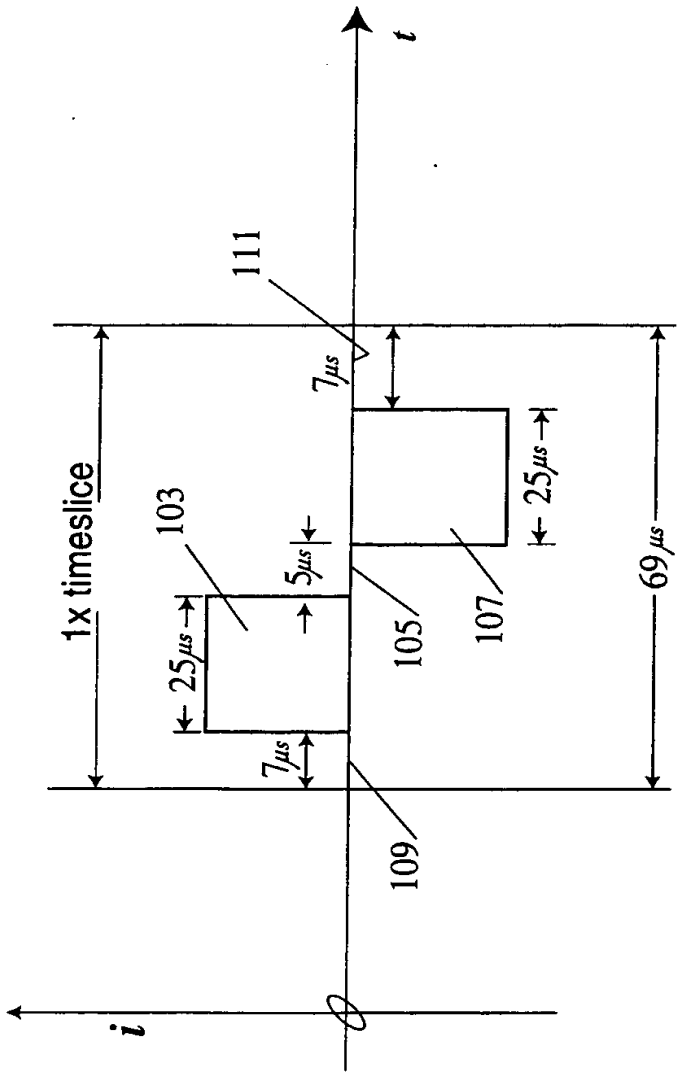


Fig 4.

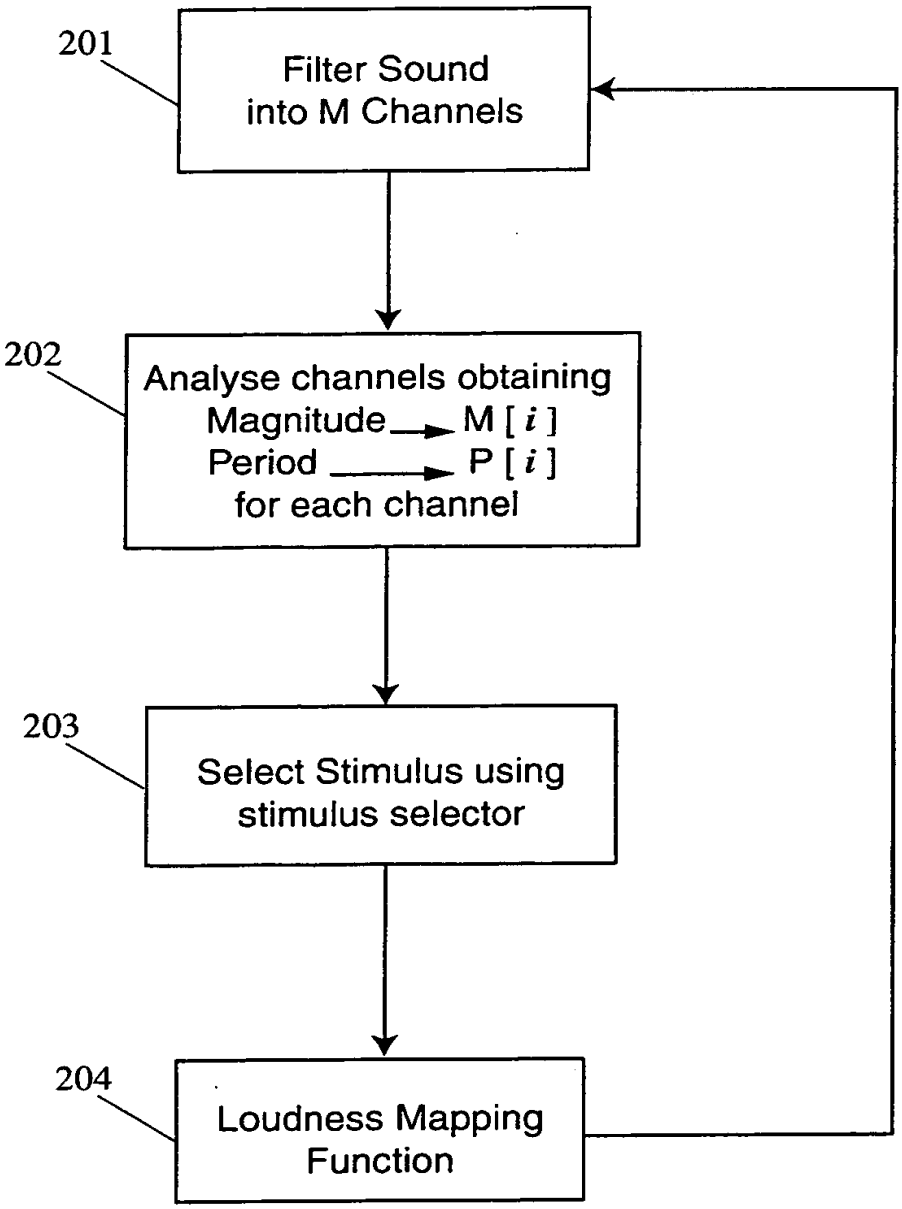
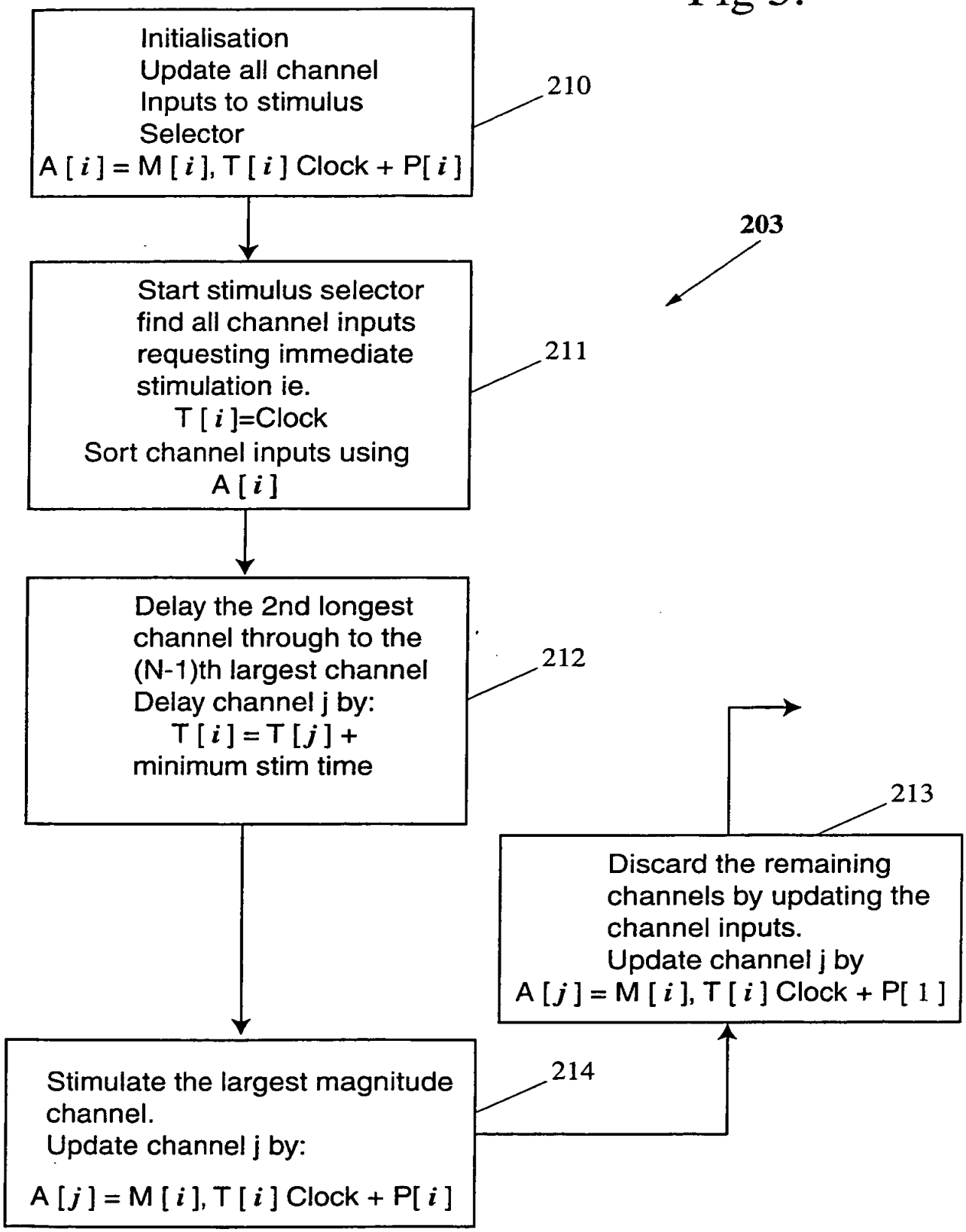

201
Filter Sound into M Channels
202
Analyse channels obtaining
Magnitude → M [i]
Period → P [i]
for each channel
203
Select Stimulus using stimulus selector
204
Loudness Mapping Function

Fig 5.


Initialisation
Update all channel
Inputs to stimulus
Selector
A [i] = M [i], T [i] Clock + P[i]
210
203
Start stimulus selector
find all channel inputs
requesting immediate
stimulation ie.
T [i]=Clock
Sort channel inputs using
A [i]
211
Delay the 2nd longest
channel through to the
(N-1)th largest channel
Delay channel j by:
T [i] = T [j] +
minimum stim time
212
213
Discard the remaining
channels by updating the
channel inputs.
Update channel j by
A [j] = M [i], T [i] Clock + P[1]
Stimulate the largest magnitude
channel.
Update channel j by:
A [j] = M [i], T [i] Clock + P[i]
214

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU00/00838

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: A61F 11/04, H04R 25/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC A61F, H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPAT: cochlear, implant, hearing aid, signal processing, period, time interval, amplitude, magnitude, estimation

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5800475 A (Jules) 1 September 1998 The whole document	1-16
A	US 5749912 A (Zhang et al.) 12 May 1998 The whole document	1-16
A	US 4400590 A (Michelson) 23 Augest 1983 The whole document	1-16

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 August 2000	15 AUG 2000
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer J. LAW Telephone No : (02) 6283 2179

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU00/00838

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	5800475	AU	54531/96	EP	745363	FR	2734711
		JP	8322873				
US	5749912	AU	38899/95	US	5549658	WO	9612456
US	4400590	NONE					

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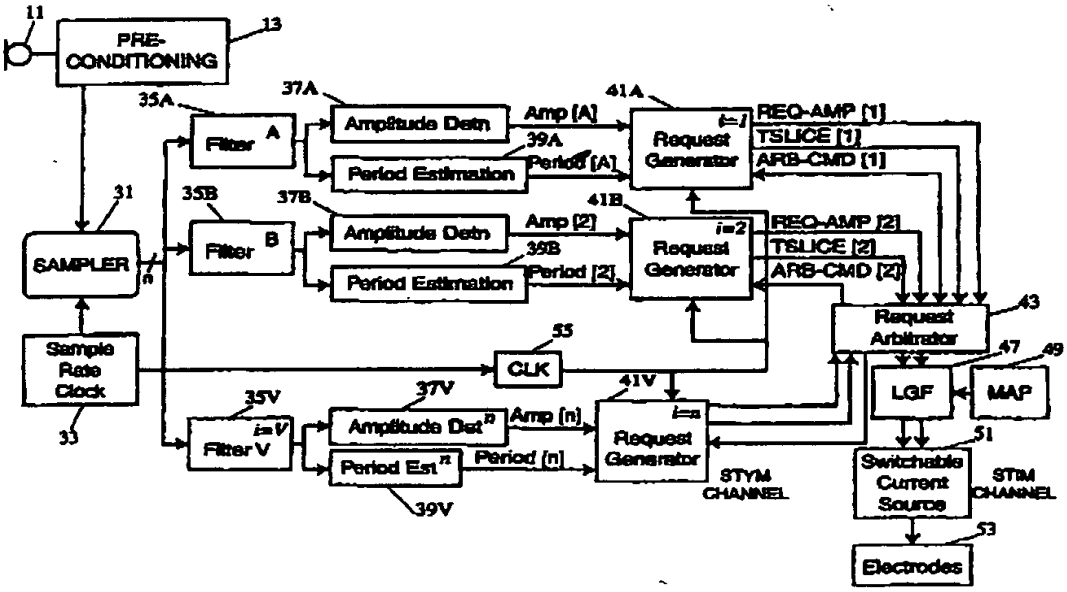
— *With international search report.*

[Continued on next page]

(54) Title: MULTIRATE COCHLEAR STIMULATION STRATEGY AND APPARATUS



(57) Abstract: An improved processing approach is disclosed in order to allow for different rates of stimulation to be used for different electrodes in a multi-electrode cochlear implant. When the incoming signal is processed by filter array (35), each channel is processed to determine amplitude (37) and to estimate the period of the signal in that channel (39). The amplitude and period information is used to determine which electrode is stimulated, and the timing of that stimulation.

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(48) Date of publication of this corrected version:
28 June 2001

(15) Information about Correction:
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MULTIRATE COCHLEAR STIMULATION STRATEGY AND APPARATUS

Technical Field

The present invention relates to cochlear implant prostheses and in particular to an apparatus and method for applying stimulation to the neural structures of a cochlea in order to improve a subject's pitch and speech perception.

Background Art

Cochlear implant systems are used to aid patients having a hearing deficiency. More particularly, these systems include a microphone receiving ambient sounds and converting the sounds into corresponding electrical signals, signal processing means for processing the electrical signals and generating cochlear stimulating signals and an electrode assembly for applying the cochlea stimulating signals to the cochlea of an implantee. In response to these electrical stimulations a perception of corresponding ambient sound is elicited in the implantee.

The inner ear of a normally hearing person includes hair cells which convert the displacement of the ear's basilar membrane in response to sound into nervous impulses. Different parts of the basilar membrane of the normal cochlea are displaced maximally by different frequencies of sound so that low frequency sounds maximally displace apical portions whereas higher frequency sounds cause displacement of more basal portions of the membrane. The nervous system is arranged so that a nervous impulse originating from a hair cell located adjacent an apical area of the membrane is perceived as a low frequency sound whereas a nervous impulse originating from a hair cell located adjacent a more basal position of the membrane is perceived as a higher frequency sound. This mapping of position to pitch is well known in the art as the tonotopic arrangement of the cochlea.

In a dysfunctional ear the hair cells may be damaged or absent so that no nervous impulses are generated. In such cases electrical stimulation impulses must be provided artificially to simulate the nervous activity of the hair cells in order to create a perception of sound.

With reference to figure 1, a typical cochlear implant is shown, which consists of an external component including a speech processor 1, and an

internal component including an implanted receiver and stimulator unit 6 and an intracochlear array 10. The external component further includes a microphone 2 which is shown integral with the speech processor 1. In this illustration the speech processor is arranged so that it can fit behind the ear with the microphone integral therewith. Alternative versions are also envisaged whereby the speech processor is worn on the body and separately attached to the microphone, and also where the speech processor and microphone are implanted in the patient. The present invention is applicable to all these alternatives.

In such cochlear implant devices, ambient sounds are detected by a microphone and a transduced signal is thereby generated, representative of the ambient sound. A processor unit then processes this transduced signal according to one of many strategies, (some of which will be explained further below) and based on this processing stimulation currents are applied between the electrodes of a coupled array. For example, in "monopolar" mode stimulation, stimulation currents may be caused to flow between an electrode of the electrode array 10 and an extracochlear electrode 115. Nervous discharges elicited in the basilar membrane 8 are conveyed to the central nervous system of the wearer by auditory nerve 9.

In the event that the stimulation current flows between an apical electrode such as electrode 111 and extracochlear electrode 115 then a lower pitched hearing sensation will be perceived by a wearer of the prosthesis than will be the case if stimulation current flows between basal electrode 107 and extracochlear electrode 115 because of the previously mentioned tonotopic arrangement of the cochlea. Further pitch information may be transmitted to the wearer corresponding to the rate at which stimulations are delivered.

Many possibilities exist as to the manner in which the signal processing means operates upon the electrical signals in order to produce stimulation signals. However it has been noted in the past that simultaneous stimulation of electrodes is not generally conducive to eliciting a perception of sound that is faithful to the actual acoustic signals being processed. This is because if electrodes are stimulated simultaneously, current paths between electrodes can interact, causing undesirable stimulation. Consequently most cochlear prosthesis stimulation strategies stimulate by means of only one electrode at a

time.

In the past designers of cochlear implant stimulation strategies have striven to optimise the intelligibility of spoken words as perceived by the wearer of a cochlear implant.

One of the earliest sound processing and cochlear stimulation strategies is described in US patent 4,532,930 to the present applicant. In that patent there is taught the use of a filter (F0) dedicated to extracting the voice pitch of a speech signal. The periodicity of the voice pitch is used to set the stimulation periodicity for two or three electrodes. A second, and possibly third, channel is analysed to determine periodicity and amplitude in a selected frequency band.

The periodicity extracted from the second filter, and possibly third filter, is used to select which electrode is stimulated for the second and third channels while the periodicity of stimulation of the channel is determined by the periodicity of the output signal from the F0 filter.

Another stimulation arrangement is described in US 4,207,441. In that system there are n electrodes each coupled to one of n filters. Each electrode is stimulated once per analysis period, with an intensity corresponding to the amplitude of the corresponding filter channel. The analysis period of this system is predetermined and hence is not related to the signal on the filter outputs.

More recently in EP 0 745 363 there is described a stimulation system which takes into account the temporal behaviour of the cochlea. In an embodiment of the invention therein described a wavelet transformation is used to extract the temporal information with a view to using this information to determine the sequence of stimulation of the electrodes. The purpose of the invention is to improve the temporal resolution in response to a rapidly changing audio spectrum.

A problem that has been faced by users of cochlear implants featuring prior art stimulation schemes is that while intelligibility of spoken words is often good the user's pitch perception, and in particular perception of music, is poor. Accordingly, it is an object of the present invention to provide an apparatus and method for use in a multi-channel cochlear implant which will improve a user's perception of pitch.

Summary of the Invention

Broadly, the present invention seeks to use information about the periodicity of the signal in each filter channel as a factor in determining the rate of stimulation applied to a tonotopically placed electrode which corresponds to the relevant channel. This allows for an improved perception of pitch by the implant user. As a result, the rate of stimulation which occurs in practice for each electrode will be related to the periodicity of the signal in the filter channel corresponding to that electrode.

According to one aspect of the present invention there is provided a cochlear implant prosthesis of the type having a transducer for converting an acoustic signal to an electrical signal, a plurality of bandpass filtering means responsive to said electrical signal and operatively producing a plurality of bandpass filtered signals, signal processing means responsive to said plurality of bandpass filtered signals and operatively generating stimulation commands, electrode driving means responsive to said stimulation commands and an electrode array coupled to said electrode driving means for operatively delivering to a user of said cochlear implant prosthesis stimulations in accordance with said stimulation commands, said signal processing means including:

a) period estimation means, responsive to said filtered signals and operatively generating periodicity signals indicative of the periodicity of each of at least a number of said plurality of filtered signals;

b) amplitude estimation means responsive to said filtered signals and operatively generating magnitude signals indicative of the magnitude of each of said plurality of filtered signals;

c) selection means responsive to said magnitude signals arranged to select only one filtered signal of said plurality of filtered signals in each stimulation period, said selection means generating said stimulation commands including a command to stimulate by means of an electrode operatively tonotopically best corresponding to said one filtered signal, said command to stimulate further specifying a time for stimulation to occur dependent on a corresponding one of said periodicity signals.

According to another aspect, the present invention provides a processing device for a cochlear implant prosthesis, said prosthesis being of the type

including electrode driving means responsive to stimulation commands and an electrode array coupled to said electrode driving means for operatively delivering to a user of said cochlear implant prosthesis stimulations in accordance with said stimulation commands,

said processing device being responsive to a transducer for converting an acoustic signal to an electrical signal and including a plurality of bandpass filtering means responsive to said electrical signal and operatively producing a plurality of bandpass filtered signals, signal processing means responsive to said plurality of bandpass filtered signals and operatively generating stimulation commands, said signal processing means including:

a) period estimation means, responsive to said filtered signals and operatively generating periodicity signals indicative of the periodicity of each of at least a number of said plurality of filtered signals;

b) amplitude estimation means responsive to said bandpass filters operatively generating magnitude signals indicative of the magnitude of each of said plurality of filtered signals;

c) selection means responsive to said magnitude signals arranged to select only one filtered signal of said plurality of filtered signals in each stimulation period, said selection means generating said stimulation commands including a command to stimulate by means of an electrode operatively tonotopically best corresponding to said filtered signal, said command to stimulate further specifying a time for stimulation to occur dependent on a corresponding one of said periodicity signals.

According to a further aspect of the present invention there is provided a method of operating a cochlear implant prosthesis of the type including a plurality of bandpass filters each having a characteristic centre frequency, said filters generating a corresponding plurality of filtered signals, said prosthesis further including stimulation delivery means coupled to an electrode array, said method including the steps of :

a) in each of a number of time intervals, determining the amplitude for each of said plurality of filtered signals and a periodicity value for at least some of said plurality of filtered signals;

b) selecting only one of said signals as a basis for stimulation in each stimulation period; and

c) applying a stimulation current by means of an electrode of said electrode array tonotopically closest to the centre frequency of the bandpass filter producing the signal determined in step b), said stimulation current being applied during a time interval determined from the periodicity value of the signal determined in step b).

Brief Description of the Drawings

Figure 1 depicts a typical cochlear implant device.

Figure 1A depicts a block diagram of the functional elements of a cochlear implant according to the present invention.

Figure 2 depicts a dedicated hardware version of a cochlear implant prosthesis according to the present invention.

Figure 3A is a graph of a possible output of an amplitude estimator module of Figure 2.

Figure 3B is a graph of a possible output of a period estimator module of Figure 2 of the same channel as the amplitude estimator of Figure 3A.

Figure 3C is a graph of stimulation currents generated via an electrode in accordance with the amplitude and period estimates of Figures 3A and 3B.

Figure 3D is a graph of stimulation currents generated via a further electrode having a stimulation current occurring simultaneously with a stimulation current in the graph of Figure 3C.

Figure 3E is a graph of a single stimulation current.

Figure 4 is a flowchart of procedural steps used in implementing the present invention by means of software on an apparatus of the type depicted in Figure 1A.

Figure 5 is a flowchart of procedural sub-steps involved in one of the boxes appearing in Figure 3.

Detailed Description

The present invention will be described with reference to a specific implementation. However, it will be appreciated that the present invention can be implemented in various ways, with suitable modifications to suit the cochlear implant system in question.

With reference to Figure 1A, there is depicted a simplified digital hardware implementation of a cochlear prosthesis according to the present invention. Sound waves are transduced by microphone 11 and the electrical signal so produced is processed by a signal conditioning module 13. Signal conditioning module 13 includes standard circuits for pre-amplifying and low pass filtering the signal prior to its processing by analog to digital converter 15. Analog to digital converter 15 produces a 16 bit digital signal which is conveyed to microprocessor 17. Microprocessor 17 operates according to a program stored in EPROM 19. Microprocessor 17, in accordance with its program operates upon the digital signal in order to generate a sequence of stimulation commands which are delivered to a switchable current source module 23. The commands delivered to the switchable current source module 23 specify the amplitude of the current that is to flow from one or more electrode to one or more other electrodes, the timing of the stimulation current, and the mode of the stimulation.

The term 'mode' here refers to the selection of electrodes between which a stimulation current is to flow. Well known stimulation modes include bipolar, monopolar and common ground. Upon receiving commands specifying the parameters of the stimulation to be applied, switchable current source module 23 connects various electrodes of electrode array 21 to an internal controllable current source in order to generate the appropriate stimulation. The construction of a switchable current source is well known in the art and may be found in the applicant's US Pat No. 4,532,930.

Figure 2 depicts a dedicated hardware implementation of the invention for purposes of explanation. While Figure 2 illustrates the invention as if individual tasks performed by microprocessor 17 were embodied in dedicated hardware, it remains the case that the invention is most readily practised according to the arrangement of Figure 1A. The invention will however be explained with reference to Figure 2 in order to most clearly impart an understanding of its operation to the reader.

Referring to Figured 2 it will be noted that the analog signal from pre-conditioning module 13 is first sampled at 16 kHz by sampler 31 thereby producing a sampled signal. The sampled signal is split 22 ways, each of the split signals providing an input to digital filters 35A-35V which filter the signal into

quarter octave frequency bands. It will be appreciated that the numbers of ways the signal is split, and the sampling rate, are matters of design choice appropriate to the system in which the present invention is implemented.

Digital filters 35A-35V are bandpass and logarithmically spaced with the base frequency being typically at 150 Hz. Each filter is of a 6th order Chebychev Type I bandpass type implemented in three second order sections. The quarter octave frequency bands are as shown below:

Filter Band	Lower Frequency Boundary (Hz)	Upper Frequency Boundary (Hz)
A	150.00	178.38
B	178.38	212.13
C	212.13	252.27
D	252.27	300.00
E	300.00	356.76
F	356.76	424.26
G	424.26	504.54
H	504.54	600.00
I	600.00	713.52
J	713.52	848.53
K	848.53	1009.10
L	1009.10	1200.00
M	1200.00	1427.00
N	1427.00	1697.10
O	1697.10	2018.20
P	2018.20	2400.00
Q	2400.00	2854.10
R	2854.10	3394.10
S	3394.10	4036.30
T	4036.30	4800.00
U	4800.00	5708.20
V	5708.20	6788.20

The bandpass filtered signal from each of the digital filters, for example 35A, is connected to an amplitude detection module 37A and a period estimation module 39A. The output AMP[A] of amplitude detection module 37A is a digital signal representing an estimation of the amplitude of the sampled signal from filter 35A. The construction of module 37A is straightforward, well understood by those skilled in the art, and will not be explained in detail other than to say that it could be based on a series of comparators.

Period estimation module 39A counts sampling periods between positive zero crossings of the signal from filter 35A. The output signal PERIOD[A] is scaled so that it is expressed in units of "timeslices".

One "timeslice" is the time taken to deliver one stimulation pulse by means of an electrode. With reference to Figure 3E an example of a stimulation current pulse waveform comprises a first 'phase' 103 being a square wave of predetermined amplitude, an interphase gap 105 and a second phase 107 being

a current square wave of the same magnitude and duration as the first phase but flowing in the opposite direction between an intra-cochlear electrode and (in mono-polar mode) an extra-cochlear electrode. Time periods 109 and 111 are present in which the system generating the stimulations has time to perform any necessary operations in order to configure for the next stimulation. The overall time taken to set-up, deliver and recover from application of a stimulation is one timeslice, in the present example a timeslice is of approximately 69 microseconds duration.

In the present implementation the preferred maximum stimulation rate is 8kHz whereas the preferred sampling rate is 16kHz. Accordingly PERIOD[A] is the number of samples occurring between positive-going zero crossings divided by two and rounded. The PERIOD[A] signal is updated at the end of each period.

The AMP[A],...,AMP[V] and PERIOD[A],...,PERIOD[V] signals contain magnitude and period information concerning the ambient sound picked up by microphone 11 for each of the frequency bands monitored by bandpass filters 35. It is possible to simply stimulate via each corresponding electrode e[i] with a current intensity corresponding to AMP[i] at a time PERIOD[i] into the future in order to convey the information generated by amplitude detectors 37 and period estimators 39 to a wearer of the cochlear prosthesis. For example, with reference to Figures 3A, 3B and 3C a stimulation sequence via electrode e[A] is shown corresponding to amplitude and period values generated by amplitude detection module 37A and period estimation module 39A as shown plotted in Figures 3A and 3B. Period[A] is equal to P1 at time t=0 and Amp[A] is equal to a1. Accordingly at a time t=P1 a stimulation current is delivered via electrode e[A] of electrical amplitude I(a1) where I() is a loudness growth function which maps amplitude into the dynamic range of the wearer of the prosthesis.

The period P2 and amplitude a2 values are then obtained and a further stimulation is delivered at time t=P1+P2 of amplitude I(a2). This process is repeated continuously to produce the stimulation sequence of biphasic current pulses shown in the graph of Figure 3C. As previously mentioned, such a process could be simultaneously performed independently on all channels of the implant, (a "channel" as used here refers to a stimulation electrode, its

corresponding filter and period and amplitude estimation modules).

In the system thus far described the period estimation module 39A produces a period estimate which is simply the time delay between the last two positive-going zero crossings. While this system works well, any noise on the individual period estimates will degrade the performance of the system. To prevent this, it is desirable to calculate a smoothed period estimate.

The individual period estimates constitute a number sequence which is amenable to any of the methods of smoothing known to the art of digital signal processing. The smoothing may, for example, be implemented as a simple FIR or recursive digital filter - preferably a low-pass filter. Alternatively a rank-order filter, such as a median filter may be used. A rank-order filter has the advantage that it will completely remove any single data errors from the number sequence. A smoothed period estimate is thus produced by applying the sequence of period estimates to a digital filter, and taking the output of that filter. The smoothed period estimate is then utilised by taking the most recent output from the filter and using it in place of the (unsmoothed) period estimate.

With reference to Figure 3D there is shown a stimulation sequence via electrode e[B]. It will be noted that stimulation pulse 102 occurs at exactly the same time as stimulation pulse I(a2) of Figure 3C. Such coincidences occur more and more frequently depending on the number of channels used.

There are at least two problems associated with the above stimulation strategy by which stimulations may be delivered by two or more electrodes simultaneously. Firstly, as discussed above, it is well known that simultaneous, or very near simultaneous, stimulation produces a deterioration in the quality of the sound perceived by the user, due to the interaction of simultaneous current paths between the electrodes.

Consequently the application of stimulations on a number of channels simultaneously is undesirable. A further problem is that simultaneous stimulation requires very substantial processing power and so is not possible in the majority of cochlear implants presently available.

In light of the above problems the inventors have incorporated a preferred refinement for determining which information signals, coming from amplitude

detectors 37 and period estimation modules 39 are most appropriate for acting upon in order to produce a high quality percept in a user. According to the invention, for any stimulation period i.e. "timeslice" t0 the signals AMP[A,t0],...,AMP[V,t0] are ordered according to magnitude and a stimulation current is generated by means of the electrode which corresponds to the signal AMP[A,t0],...,AMP[V,t0] having the greatest magnitude. (It should be noted that, when implanted, electrodes e[A],...,e[V] are tonotopically mapped to filters fA,...,fV so that electrode e[A] is most apically placed whereas electrode e[v] is most basally placed.) For example, if it is found that AMP[F,t0] has the greatest magnitude at a given timeslice then electrode e[F] is used to deliver the monopolar stimulation in the next timeslice t1.

A further variation to this scheme is that a number of the next largest magnitude signals are also determined in the same timeslot, for example AMP[G,t0] > AMP[B,t0] > AMP[K,t0] might be determined to have the magnitudes next greatest to AMP[F,t0]. In that case those values are assigned to AMP[G,t1], AMP[B,t1] and AMP[K,t1] respectively. During the next timeslice, t1, the procedure is repeated and it may be that AMP[G,t1] is selected as having the greatest magnitude so that electrode e[G] is selected for delivering a stimulation pulse of amplitude corresponding to AMP[G,t1]=AMP[G,t0]. By using this scheme it is possible that signals having a large magnitude, though not the greatest, are presented to the user after a short time delay. The inventors have found that most acoustic power is centred around the lower frequency bands which have longer periods associated with them whereas the higher frequency bands generally have less power associated with them as well as being of shorter period. Accordingly, it is predominantly higher frequency sounds which are delayed rather than lower frequency sounds.

A further refinement is that rather than calculate period estimates in respect of the outputs from filters centred at higher frequencies, for example for filters FI,...,FV period estimators 39I,...,39V simply generate a constant signal, or periodicity value, indicating a period of 1.25ms i.e. a periodicity value towards the highest stimulation rate that the device is capable of supporting.

While the preceding description covers a system utilising period estimators on some or all of the bandpass filtered signals, it is possible to implement the system more simply. A stimulus could be requested each time a positive zero-crossing is detected on a filter output. Once per timeslice each channel is interrogated to see if it has a stimulation request pending. If there are no requests pending, then no action is required. If there is exactly one request pending, then a stimulus is generated corresponding to that request.

If more than one request is pending, then the following actions are taken. The requests are sorted according to the amplitudes of the corresponding bandpass filtered signals. A stimulus is generated corresponding to the bandpass filtered signal with the largest amplitude. The next N largest (preferably 5 largest) amplitude requests are delayed by one timeslice. Any remaining requests are cancelled.

This system is simpler to implement than that previously described. It has two main disadvantages, however. The previously described system utilising period estimates acts to limit the stimulation rate on higher frequency channels. This is directly beneficial in that excessive stimulation with little information content is avoided. More importantly, in the case of relatively large amplitude high frequency signals, the lower frequency signals will be completely lost in the simpler system. The rate-limiting effect of the period-estimation system will mean that the low-frequency signal will always get through.

The request generators 41-A,..,41-V and request arbitrator 43 operate to determine which electrode will be stimulated from the AMP[A],...,AMP[V] and PERIOD[A],...,PERIOD[V] signals. The operation of the request generators and the request arbitrator, in order to implement the aforedescribed scheme, will now be explained with exemplary reference to request generator 41A.

The AMP[A] and PERIOD[A] signals are inputs to request generator module 41A. Another input to the request generator is the CLK signal which corresponds to the present timeslice. The CLK signal is modulus 256 to avoid overflow problems. The last input to request generator 41A is a command signal ARB_CMD[A] from request arbitrator 43.

The outputs from request generator 41A are TSLICE[A] and REQ_AMP[A].

The TSLICE[A] represents the time at which it is proposed by generator 41A that a stimulation be delivered having an amplitude value represented by REQ_AMP[A].

The relationship between TSLICE[A] and PERIOD[A] and REQ_AMP[A] and AMP[A] is determined by the value of the ARB_CMD[A] signal. The ARB_CMD[A] signal can take one of three values REQUEST, DELAY, DISCARD. When ARB_CMD[A] takes the value :

REQUEST

then REQ_AMP[A] := AMP[A]; TSLICE[A] :=CLK+PERIOD[A]

DELAY

then TSLICE[A] := TSLICE[A] + 1

DISCARD

take no action.

The principle behind these rules is that in the event that request arbitrator 43, whose operation will shortly be described, determines that a stimulation pulse should be applied corresponding to the output from filter 35A then by sending an ARB_CMD[A] signal having the value REQUEST to request generator 41A the amplitude and timing of the stimulation pulse is made available at the next timeslice. Alternatively, if ARB_CMD[A] takes the value DELAY then the corresponding TSLICE[A] variable is incremented. Construction of the request generator, in order to implement the above rules is readily accomplished according to established synchronous digital design techniques.

Request arbitrator module 43 takes as its input the signals TSLICE[A],.., TSLICE[V] from each of the request generators 41A-41V, REQ_AMP[A],.., REQ_AMP[V] and the CLK signal. Arbitrator module 43 generates a signal P_CHAN which identifies which of electrodes e[A],..,e[V] of the electrode array is to be used to apply a stimulation.

The arbitrator module also generates a signal P_AMP which takes a value REQ_AMP[A],..,REQ_AMP[V] which is used, after scaling as will subsequently be described, to determine the amplitude of the signal to be used when applying stimulation. Request arbitrator module 43 operates according to the following rules:

1. Find all TSLICE[i] with a value equal to CLK.

2. Find N channels of those determined in Step 1 which have the largest value of REQ_AMP[j]. The channel with the largest value of REQ_AMP[j] and TSLICE[j] as determined in step 1 is found and P_CHAN set to j and P_AMP set to REQ_AMP[j]. So that a stimulation is directed via electrode e[j] with amplitude scaled from the value P_AMP=REQ_AMP[j]. This is accomplished by setting the ARB_CMD[j] signal to REQUEST.

3. The channels having the next N-1 largest amplitude values REQ_AMP[] are delayed by one timeslice for consideration during set up for the next stimulation. This is achieved by sending an ARB_CMD[] signal to the corresponding N-1 request generators to DELAY.

4. The remaining channels, which were selected in step 1 but not in step 2 are discarded. This is achieved by sending the corresponding request generators an ARB_CMD[] signal of value DISCARD.

5. If any of the request generators is sending a specific "no pulse request" then the corresponding ARB_CMD[] signals are set to REQUEST.

Once the P_CHAN and P_AMP values have been determined they are passed to Loudness growth function module 47. The growth function module takes into account the predetermined comfort and threshold levels of the user of the cochlear prosthesis in order to map the P_AMP values into the listeners dynamic range. Such mapping is known in the prior art and the reader is referred to US Patent No. 4,532,930 to the same applicant for further details.

The invention is most conveniently practised, in accordance with the embodiment of Figure 1, by programming a SPrint speech processor, available from Cochlear Limited of 14 Mars Road, Lane Cove, NSW 2066, Australia, in order to perform the operations described in relation to Figure 2. The SPrint speech processor is used in conjunction with a CI24M cochlear implant receiver-stimulator from the same vendor.

With reference to Figure 4 there is depicted a block diagram of the overall operational procedure for implementing the present invention in software. At block 201, for each sample period, the sound signal is filtered into the required number of channels. At block 202, the signal in each channel is analysed to determine its

amplitude, and the period of the signal. The latter may be performed by determining the time between successive zero crossings, as described above. Based upon the values for the amplitude and period for each channel, block 203 selects which channel signal is to be used as the basis for stimulation, and hence the electrode to be stimulated. Loudness mapping block 204 performs the function of mapping the desired amplitude stimulus within the dynamic range for the selected electrode. The latter step is well known to those skilled in the art.

Figure 5 further details the operational steps performed in box 203 of Figure 4. At initialisation, in block 210, the stimulus selector updates all inputs. The inputs are the values for amplitude and period as described previously. At block 211, each input channel is checked to determine if a stimulation is being requested for the next period, based upon the period value, and all such channels are sorted according to amplitude. At block 212, all channels but the largest amplitude channel are delayed to a later stimulation period. In block 214, the largest amplitude channel is selected as the basis for stimulation, and the inputs for that channel are updated to reflect that a stimulus will be delivered that period. Block 213 completes the process by discarding the remaining channels by updating their inputs, and returning to the process of block 210 for the next period, time j.

While the invention has been described with reference to preferred embodiments, it is to be understood that these are merely illustrative of the application of principles of the invention. Accordingly, the embodiments described in particular should be considered exemplary, not limiting, with respect to the following claims.

Claims

1. A cochlear implant prosthesis of the type having a transducer for converting an acoustic signal to an electrical signal, a plurality of bandpass filtering means responsive to said electrical signal and operatively producing a plurality of bandpass filtered signals, signal processing means responsive to said plurality of bandpass filtered signals and operatively generating stimulation commands, electrode driving means responsive to said stimulation commands and an electrode array coupled to said electrode driving means for operatively delivering to a user of said cochlear implant prosthesis stimulations in accordance with said stimulation commands, said signal processing means including:

a) period estimation means, responsive to said filtered signals and operatively generating periodicity signals indicative of the periodicity of each of at least a number of said plurality of filtered signals;

b) amplitude estimation means responsive to said filtered signals and operatively generating magnitude signals indicative of the magnitude of each of said plurality of filtered signals;

c) selection means responsive to said magnitude signals arranged to select only one filtered signal of said plurality of filtered signals in each stimulation period, said selection means generating said stimulation commands including a command to stimulate by means of an electrode operatively best corresponding to said one filtered signal, said command to stimulate further specifying a time for stimulation to occur dependent on a corresponding one of said periodicity signals.

2. A cochlear implant prosthesis according to claim 1, wherein said period estimation means operatively determines a value for the time between successive zero crossings by the filtered signal, and responsive to this value generates said periodicity signal.

3. A cochlear implant according to claim 2, wherein said period estimation means is further responsive to previous values of said time between successive zero crossings, so that a smoothed period estimate value is generated, and responsive to this value said period estimation means generates said periodicity signal.

4. A cochlear implant according to claim 3, wherein said periodicity signal is scaled to an integral multiple of the time taken to deliver one stimulation pulse.

5. A cochlear implant according to claim 1, wherein said selection means is responsive to the amplitude and selects said one filtered signal on the basis that said signal has the greatest amplitude.

6. A cochlear implant according to claim 1, wherein the rates of stimulation operatively delivered to each electrode differ from each other in response to said periodicity signals.

7. A processing device for a cochlear implant prosthesis, said prosthesis being of the type including electrode driving means responsive to stimulation commands and an electrode array coupled to said electrode driving means for operatively delivering to a user of said cochlear implant prosthesis stimulations in accordance with said stimulation commands,

said processing device being responsive to a transducer for converting an acoustic signal to an electrical signal and including a plurality of bandpass filtering means responsive to said electrical signal and operatively producing a plurality of bandpass filtered signals, signal processing means responsive to said plurality of bandpass filtered signals and operatively generating stimulation commands, said signal processing means including:

a) period estimation means, responsive to said filtered signals and operatively generating periodicity signals indicative of the periodicity of each of at least a number of said plurality of filtered signals;

b) amplitude estimation means responsive to said bandpass filters operatively generating magnitude signals indicative of the magnitude of each of said plurality of filtered signals;

c) selection means responsive to said magnitude signals arranged to select only one filtered signal of said plurality of filtered signals in each stimulation period, said selection means generating said stimulation commands including a command to stimulate by means of an electrode operatively best corresponding to said filtered signal, said command to stimulate further specifying a time for stimulation to occur dependent on a corresponding one of said periodicity signals.

8. A processing device according to claim 7, wherein said period estimation means operatively determines a value for the time between successive zero crossings by said filtered signal, and responsive to this value generates said periodicity signal.

9. A processing device according to claim 8, wherein said period estimation means is further responsive to previous values of said time between successive zero crossings, so that a smoothed period estimate value is generated, and responsive to this value said period estimation means generates said periodicity signal.

10. A processing device according to claim 9, wherein said periodicity signal is scaled to an integral multiple of the time taken to deliver one stimulation pulse.

11. A processing device according to claim 7, wherein said selection means is responsive to the amplitude and selects said one filtered signal on the basis that said signal has the greatest amplitude.

12. A processing device according to claim 7, wherein the stimulation commands are such that the rates of stimulation operatively delivered to each electrode differ from each other in response to said periodicity signals.

13. A method of operating a cochlear implant prosthesis of the type including a plurality of bandpass filters each having a characteristic centre frequency, said filters generating a corresponding plurality of filtered signals, said prosthesis further including stimulation delivery means coupled to an electrode array, said method including the steps of :

a) in each of a number of time intervals, determining the amplitude for each of said plurality of filtered signals and a periodicity value for at least some of said plurality of filtered signals;

b) selecting only one of said signals as a basis for stimulation in each stimulation period; and

c) applying a stimulation current by means of an electrode of said electrode array tonotopically closest to the centre frequency of the bandpass filter producing the signal determined in step b), said stimulation current being applied during a time interval determined from the periodicity value of the signal determined in step b).

14. A method according to claim 13, wherein said periodicity value is determined by acquiring a period value for the time between successive zero crossings by the filtered signal, and responsive to the period value generating said periodicity signal.

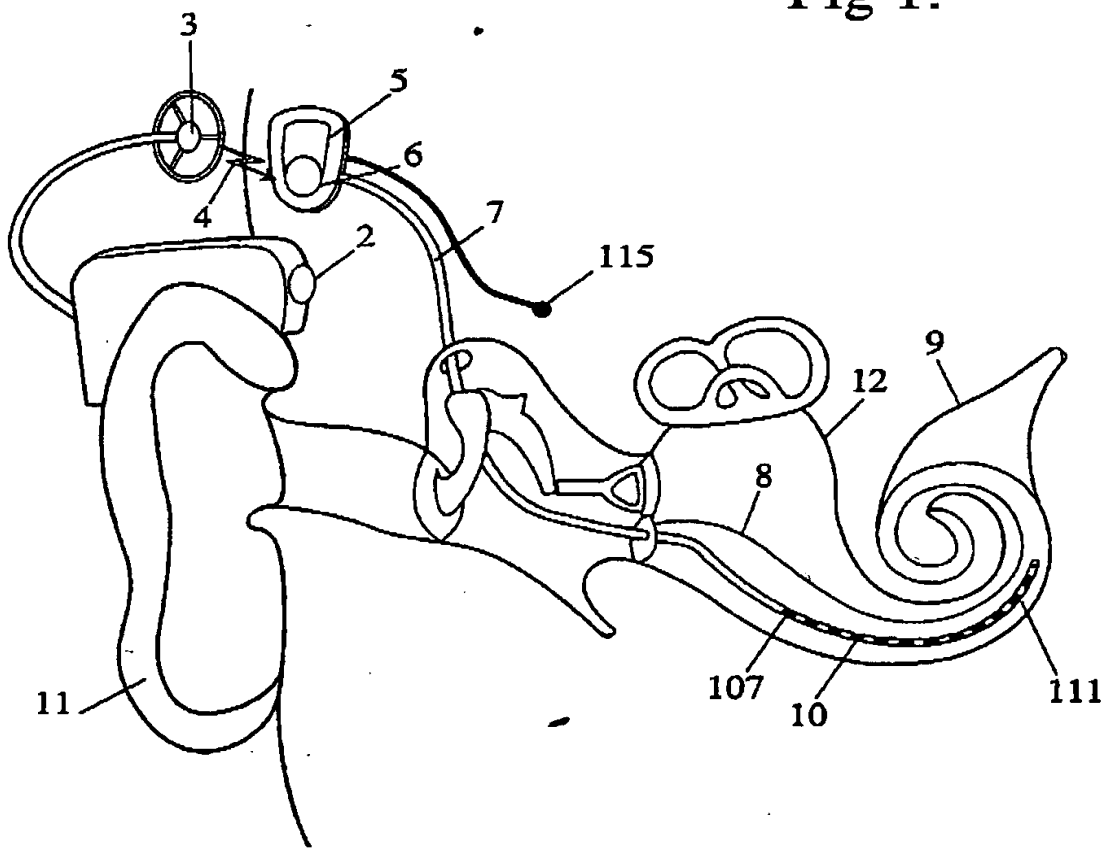
15. A method according to claim 14, wherein said periodicity value is determined using a smoothed period value, said smoothed value being determined in response to current and previous values of said period value, and responsive to said smoothed period value said periodicity signal is generated.

16. A method according to claim 15, wherein said periodicity value is determined for all of said filtered signals.

17. A method according to claim 16, wherein step (b) includes determining which of said plurality of signals has the greatest amplitude.

18. A method according to claim 13, wherein the rates of stimulation operatively delivered to each electrode differ from each other in response to said periodicity signals.

Fig 1.



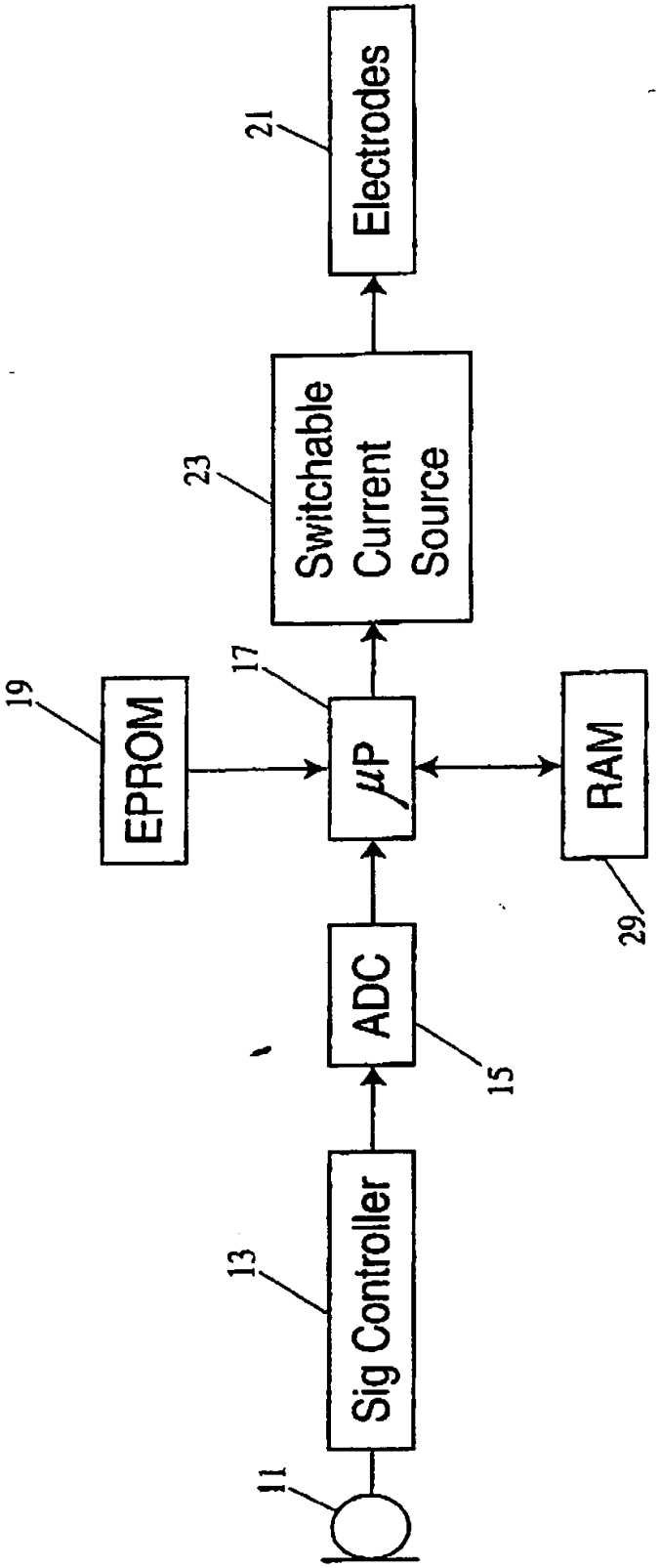

Electrodes
21
Switchable Current Source
23
EPROM
19
17
μP
RAM
29
ADC
15
Sig Controller
13
11

Fig 1a.

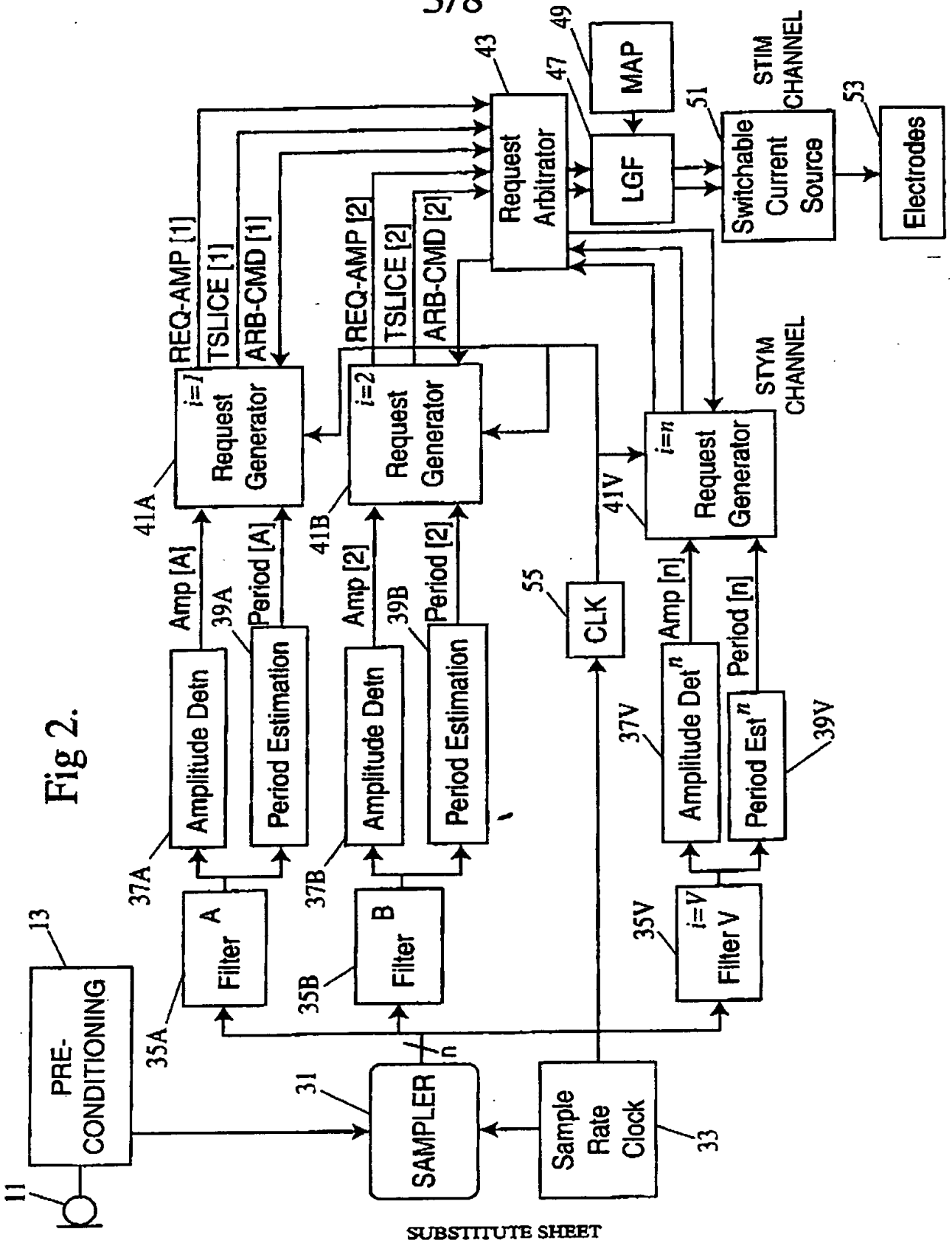

PRE-CONDITIONING
SAMPLER
Sample Rate Clock
Filter A
Filter B
Filter V
Amplitude Detn
Period Estimation
Amplitude Det^n
Period Est^n
CLK
Request Arbitrator
LGF
MAP
Switchable Current Source
Electrodes
STIM CHANNEL
STYM CHANNEL
i=1 Request Generator
i=2 Request Generator
i=n Request Generator
REQ-AMP [1]
TSLICE [1]
ARB-CMD [1]
REQ-AMP [2]
TSLICE [2]
ARB-CMD [2]
Amp [A]
Period [A]
Amp [2]
Period [2]
Amp [n]
Period [n]
11
13
31
33
35A
35B
35V
37A
37B
37V
39A
39B
39V
41A
41B
41V
43
47
49
51
53
55

Fig 2.

Fig 3A.

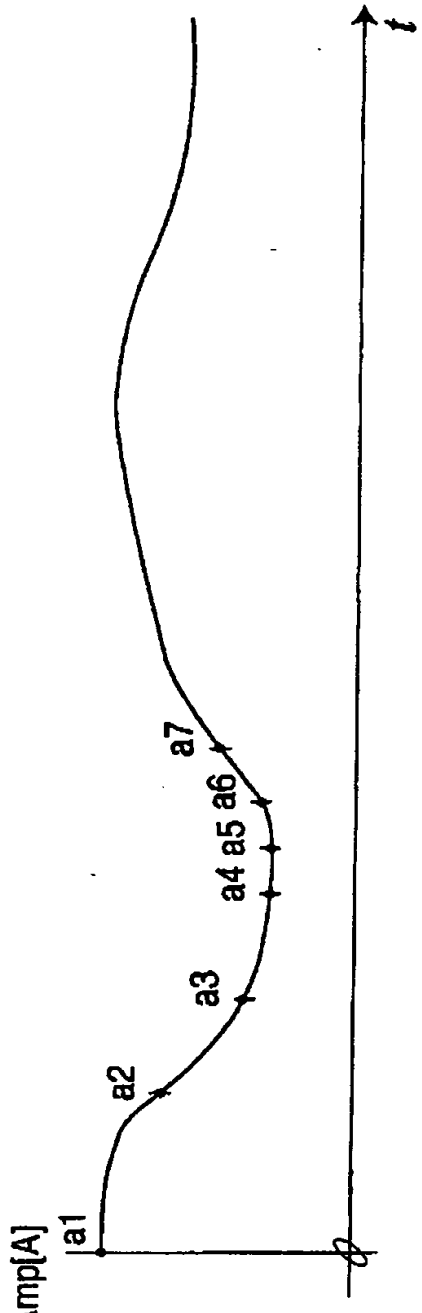
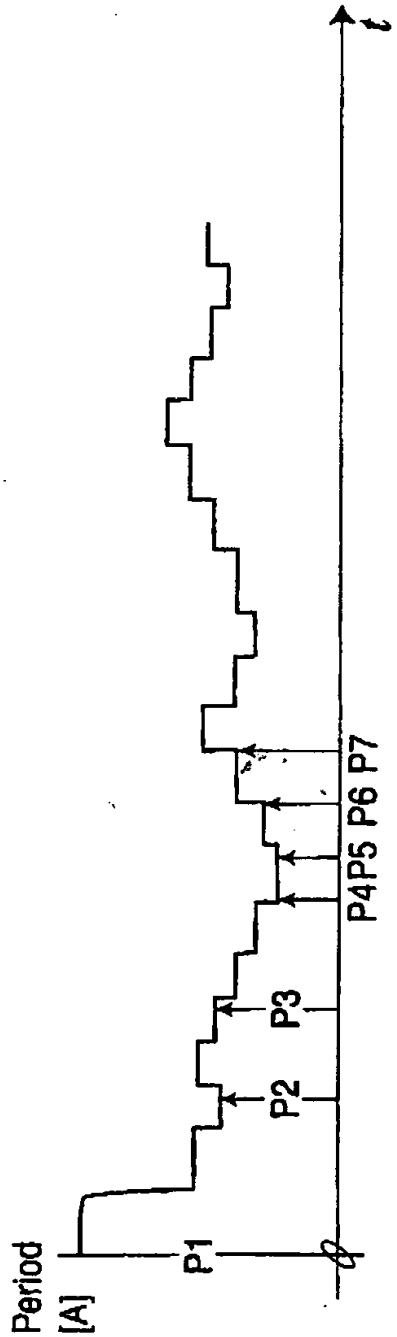


Fig 3B.



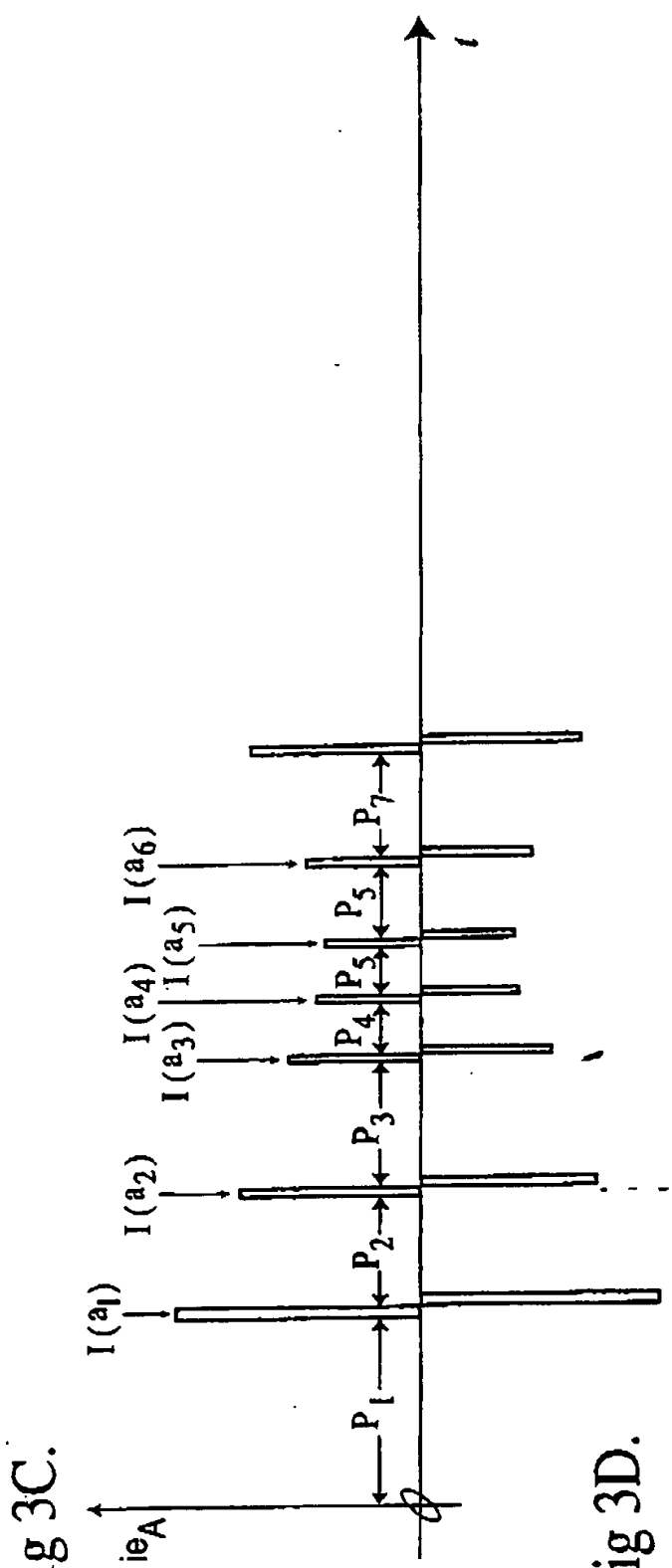

$I(a_6)$
$I(a_5)$
$I(a_4)$
$I(a_3)$
$I(a_2)$
$I(a_1)$
P_7
P_5
P_5
P_4
P_3
P_2
P_1
ie_A

Fig 3C.

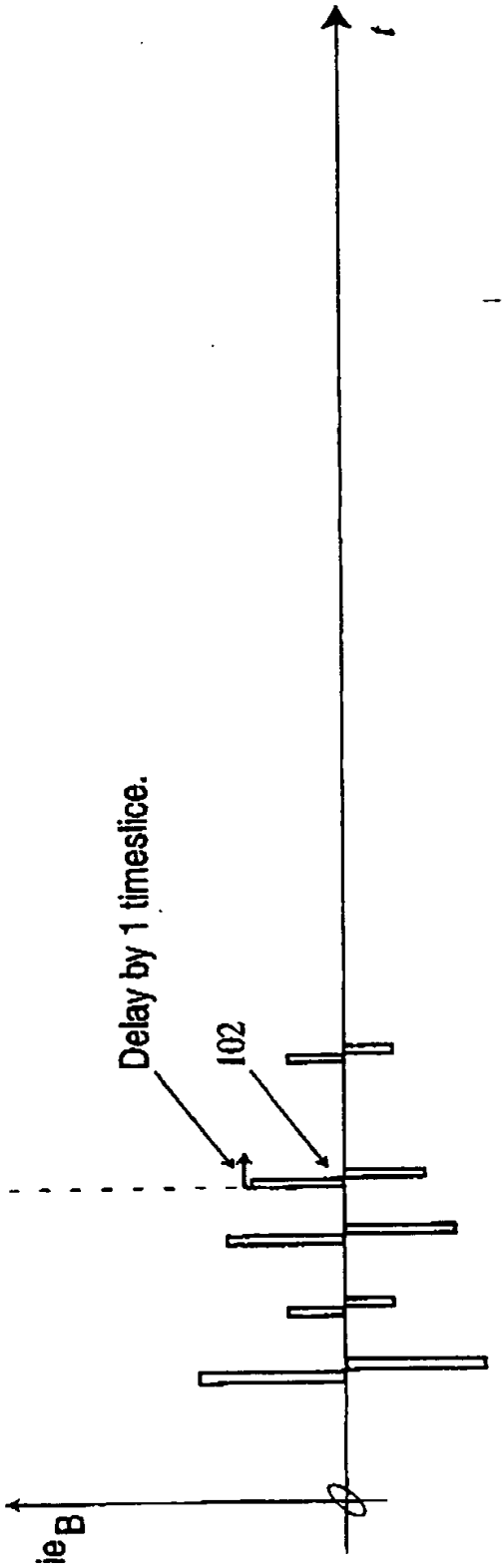

Delay by 1 timeslice.
102
ie_B

Fig 3D.

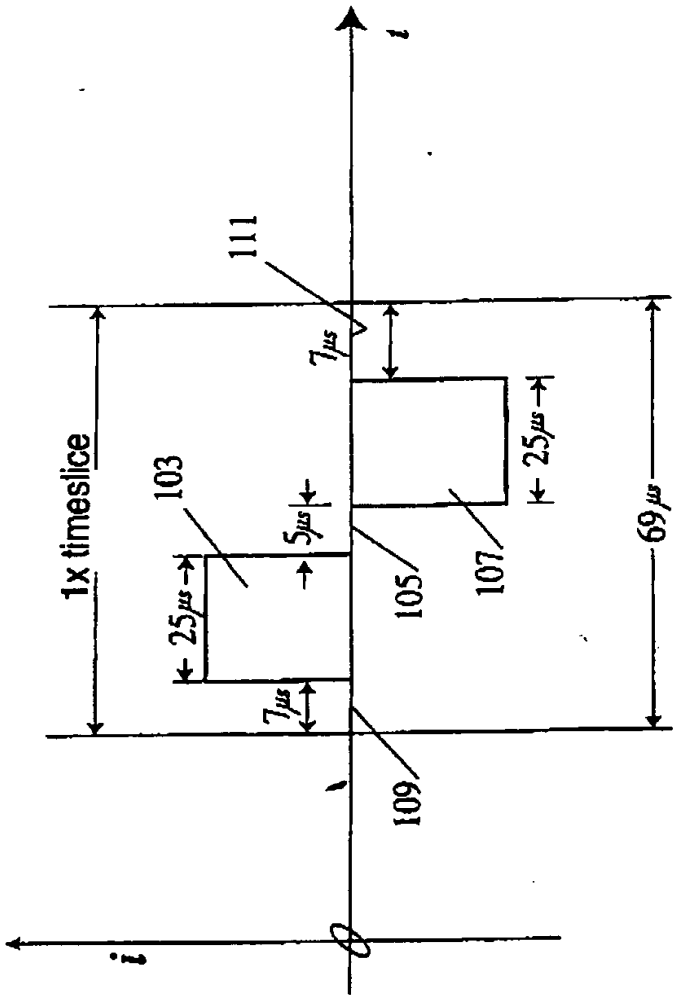

t
111
7μs
1x timeslice
103
5μs
25μs
105
107
25μs
69μs
7μs
109
i
0

Fig 3E.

Fig 4.

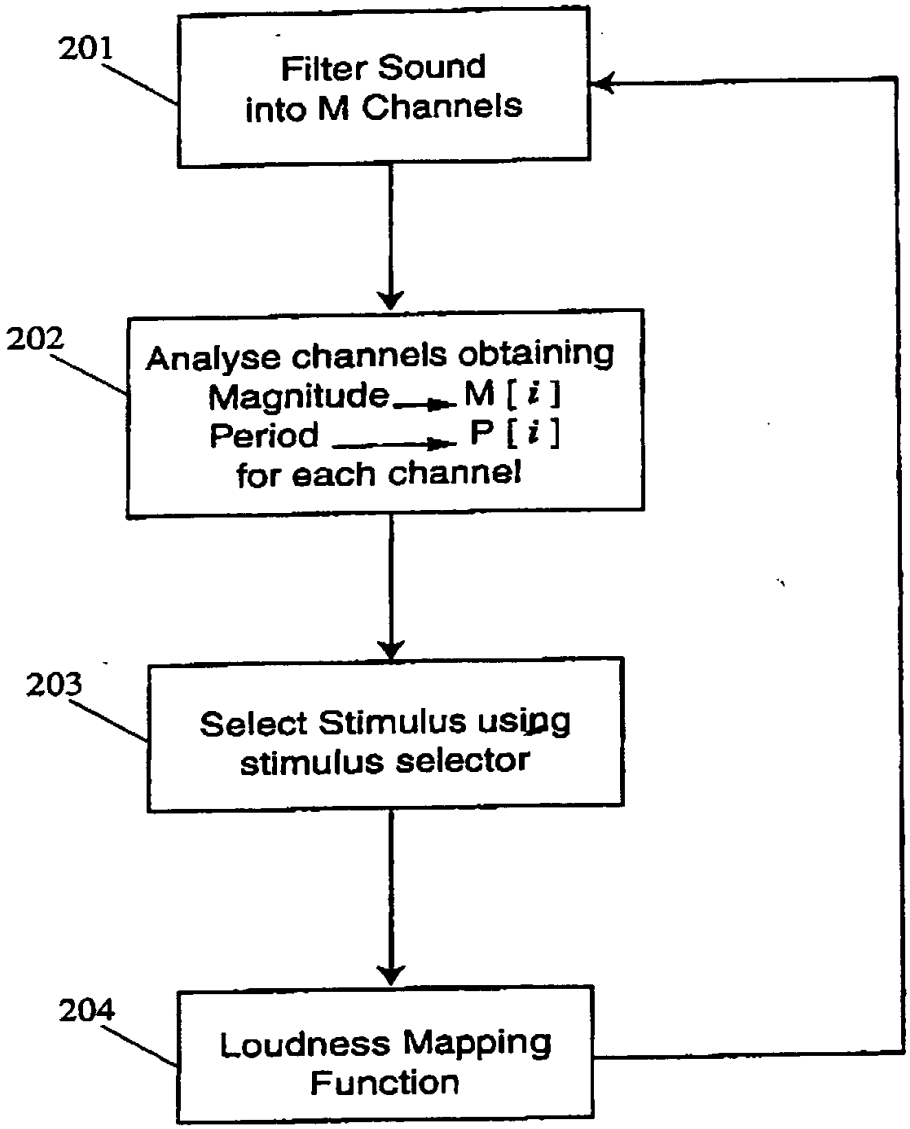
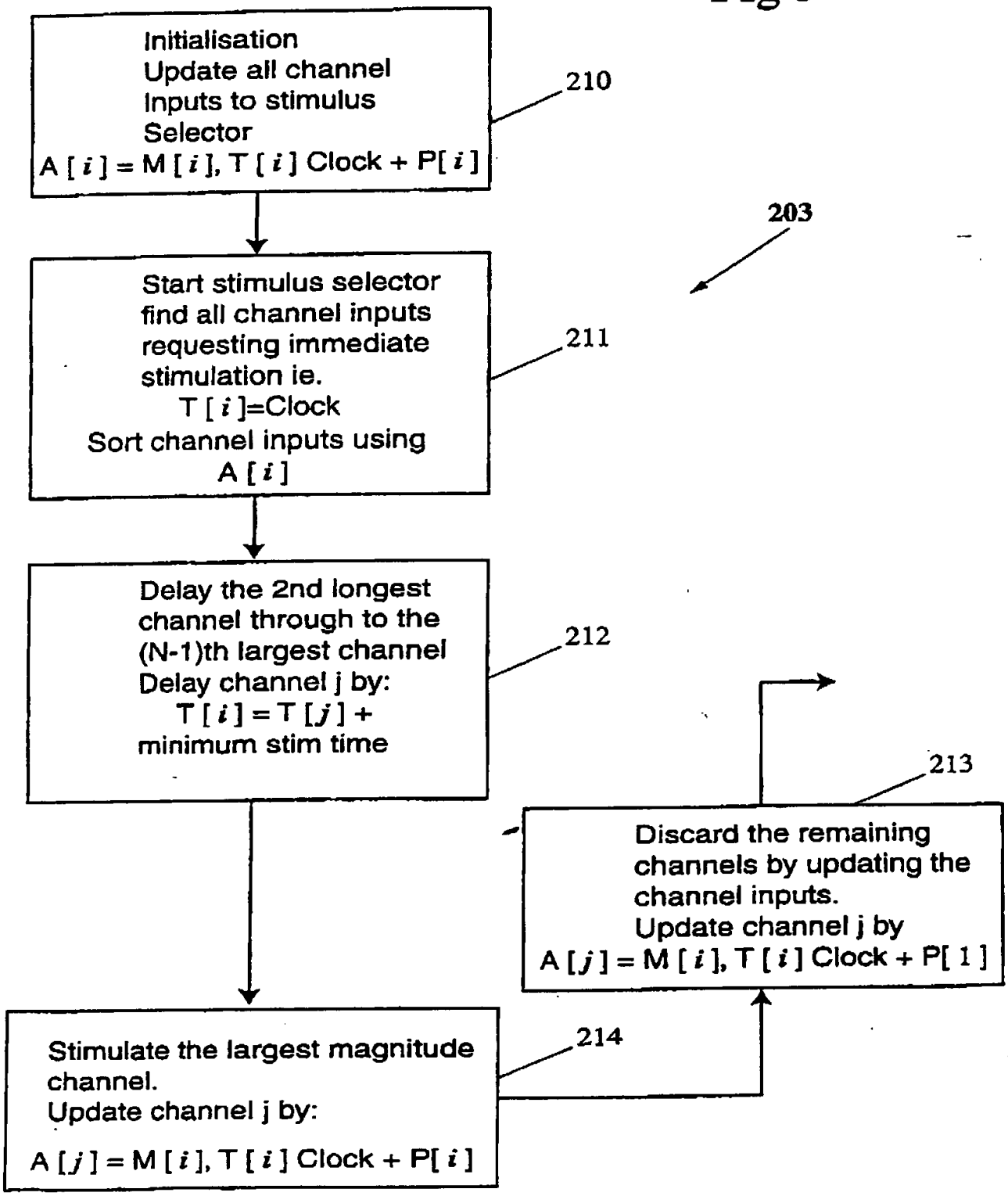

201
Filter Sound into M Channels
202
Analyse channels obtaining
Magnitude → M [i]
Period → P [i]
for each channel
203
Select Stimulus using stimulus selector
204
Loudness Mapping Function

Fig 5.


Initialisation
Update all channel inputs to stimulus Selector
A [i] = M [i], T [i] Clock + P[i]
210
203
Start stimulus selector find all channel inputs requesting immediate stimulation ie.
T [i]=Clock
Sort channel inputs using
A [i]
211
Delay the 2nd longest channel through to the (N-1)th largest channel
Delay channel j by:
T [i] = T [j] + minimum stim time
212
213
Discard the remaining channels by updating the channel inputs.
Update channel j by
A [j] = M [i], T [i] Clock + P[1]
Stimulate the largest magnitude channel.
Update channel j by:
A [j] = M [i], T [i] Clock + P[i]
214

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU00/00838

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: A61F 11/04, H04R 25/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC A61F, H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPAT: cochlear, implant, hearing aid, signal processing, period, time interval, amplitude, magnitude, estimation

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5800475 A (Jules) 1 September 1998 The whole document	1-16
A	US 5749912 A (Zhang et al.) 12 May 1998 The whole document	1-16
A	US 4400590 A (Michelson) 23 August 1983 The whole document	1-16

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 August 2000	15 AUG 2000

Name and mailing address of the ISA/AU	Authorized officer
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	J. LAW Telephone No : (02) 6283 2179

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU00/00838

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	5800475	AU	54531/96	EP	745363	FR	2734711
		JP	8322873				
US	5749912	AU	38899/95	US	5549658	WO	9612456
US	4400590	NONE					

END OF ANNEX

PATENT COOPERATION TREATY

From the:
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:
WATERMARK PATENT & TRADEMARK ATTORNEYS
Locked Bag 5
HAWTHORN VIC 3122

PCT

NOTIFICATION OF TRANSMITTAL OF INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Rule 71.1)

Date of mailing (day/month/year): 19 FEB 2001

IMPORTANT NOTIFICATION

Applicant's or agent's file reference	International Application No.	International Filing Date	Priority Date
P15646PCAU/PNF:MB	PCT/AU00/00838	13 July 2000	13 July 1999

Applicant: COCHLEAR LIMITED et al

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translations to those Offices.

4. **REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices)(Article 39(1))(see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide

Name and mailing address of the IPEA/AU	Authorized officer
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	J. Law Telephone No. (02) 6283 2179

Form PCT/IPEA/416 (July 1992)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference P15646PCAU/PNF:MB	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416).
International Application No. PCT/AU00/00838	International Filing Date *(day/month/year)* 13 July 2000	Priority Date *(day/month/year)* 13 July 1999

International Patent Classification (IPC) or national classification and IPC

Int. Cl.[7] A61F 11/04, H04R 25/00

Applicant

COCHLEAR LIMITED et al

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 3 sheets, including this cover sheet.

☐ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of sheet(s).

3. This report contains indications relating to the following items:

I	☒	Basis of the report
II	☐	Priority
III	☐	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
IV	☐	Lack of unity of invention
V	☒	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
VI	☐	Certain documents cited
VII	☐	Certain defects in the international application
VIII	☐	Certain observations on the international application

Date of submission of the demand 6 February 2001	Date of completion of the report 15 February 2001
Name and mailing address of the IPEA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized Officer J. Law Telephone No. (02) 6283 2179

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/AU00/00838

Basis of the report

With regard to the elements of the international application:*

[X] the international application as originally filed.

[ ] the description, pages , as originally filed,
pages , filed with the demand,
pages , received on with the letter of

[ ] the claims, pages , as originally filed,
pages , as amended (together with any statement) under Article 19,
pages , filed with the demand,
pages , received on with the letter of

[ ] the drawings, pages , as originally filed,
pages , filed with the demand,
pages , received on with the letter of

[ ] the sequence listing part of the description:
pages , as originally filed
pages , filed with the demand
pages , received on with the letter of

2. With regard to the language, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
These elements were available or furnished to this Authority in the following language which is:

[ ] the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).

[ ] the language of publication of the international application (under Rule 48.3(b)).

[ ] the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

3. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, was on the basis of the sequence listing:

[ ] contained in the international application in written form.

[ ] filed together with the international application in computer readable form.

[ ] furnished subsequently to this Authority in written form.

[ ] furnished subsequently to this Authority in computer readable form.

[ ] The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

[ ] The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

4. [ ] The amendments have resulted in the cancellation of:

[ ] the description, pages

[ ] the claims, Nos.

[ ] the drawings, sheets/fig.

5. [ ] This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

* *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

** *Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report*

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/AU00/00838

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

Statement		
Novelty (N)	Claims 1-18	YES
	Claims	NO
Inventive step (IS)	Claims 1-18	YES
	Claims	NO
Industrial applicability (IA)	Claims 1-18	YES
	Claims	NO

2. Citations and explanations (Rule 70.7)

Claims 1-18

The invention of the claims is a signal processing method for a cochlear implant prosthesis comprising: estimation of the periodicity of the electrical signals, which have been converted from an acoustic signal and filtered by bandpass filters; estimation of the amplitude of the filtered signals; selection of only one of the filtered signals, based on the amplitude estimations, for stimulation of an electrode in each stimulation period, which is based on the periodicity of the filtered signals.

No individual citation or combination of citations show selection of only one of the filtered signals for stimulation of an electrode in each stimulation period.

The closest art of:

US 5800475 A

shows cyclical stimulation of the electrodes in an order determined by a time distribution of the energy of a sound signal in frequency bands.

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:

WATERMARK PATENT & TRADEMARK ATTORNEYS
Locked Bag 5
HAWTHORN VIC 3122

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT OR THE DECLARATION

(PCT Rule 44.1)

Date of mailing *(day/month/year)* 17 AUG 2000

Applicant's or agent's file reference
p15646

FOR FURTHER ACTION See paragraphs 1 and 4 below

International application No.
PCT/AU00/00838

International filing date
13 July 2000

Applicant
COCHLEAR LIMITED et al

1. [X] The applicant is hereby notified that the international search report has been established and is transmitted herewith

Filing of amendments and statement under Article 19:
The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

When? The time limit for filing such amendments is normally 2 months from the date of transmittal of the international search report, however, for more details, see the notes on the accompanying sheet.

Where? Directly to the International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland
Facsimile No.: (41-22) 740.14.35

For more detailed instructions, see the notes on the accompanying sheet.

2. [ ] The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.

3. [ ] With regard to the protest against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

[ ] the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

[ ] no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Further action(s):** The applicant is reminded of the following:

Shortly after **18 months** from the priority date, the international application will be published by the International Bureau.

If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

Within **19 months** from the priority date, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase until 30 months from the priority date (in some Offices even later)

Within **20 months** from the priority date, the applicant must perform the prescribed acts for entry into the national phase before all designated Offices which have not been elected in the demand or in a later election within 19 months from the priority date or could not be elected because they are not bound by Chapter II.

Name and mailing address of the ISA/AU

AUSTRALIAN PATENT OFFICE
PO BOX 200, WODEN ACT 2606, AUSTRALIA
E-mail address: pct@ipaustralia.gov.au
Facsimile No. (02) 6285 3929

Authorized officer

J. LAW

Telephone No. (02) 6283 2179

(See notes on accompanying sheet)

NOTES TO FORM PCT/ISA/220

These Notes are intended to give the basic instructions concerning the filing of amendments under Article 19. The Notes are based on the requirements of the Patent Cooperation Treaty, the Regulations and the Administrative Instructions under that Treaty. In case of discrepancy between these Notes and those requirements, the latter are applicable. For more detailed information, see also the PCT Applicant's Guide, a publication of WIPO.

In these Notes, "Article", "Rule" and "Section" refer to the provisions of the PCT, the PCT Regulations and the PCT Administrative Instructions, respectively.

INSTRUCTIONS CONCERNING AMENDMENTS UNDER ARTICLE 19

The applicant has, after having received the international search report, one opportunity to amend the claims of the international application. It should however be emphasised that, since all parts of the international application (claims, description and drawings) may be amended during the international preliminary examination procedure, there is usually no need to file amendments of the claims under Article 19 except where, eg. the applicant wants the latter to be published for the purposes of provisional protection or has another reason for amending the claims before international publication. Furthermore, it should be emphasized that provisional protection is available in some States only.

What parts of the international application may be amended?

Under Article 19, only the claims may be amended.

During the international phase, the claims may also be amended (or further amended) under Article 34 before the International Preliminary Examining Authority. The description and drawings may only be amended under Article 34 before the International Preliminary Examining Authority.

Upon entry into the national phase, all parts of the international application may be amended under Article 28 or, where applicable, Article 41.

When? Within 2 months from the date of transmittal of the international search report or 16 months from the priority date, whichever time limit expires later. It should be noted, however, that the amendments will be considered as having been received on time if they are received by the International Bureau after the expiration of the applicable time limit but before the completion of the technical preparations for international publication (Rule 46.1).

Where not to file the amendments?

The amendments may only be filed with the International Bureau and not with the receiving Office or the International Searching Authority (Rule 46.2).

Where a demand for international preliminary examination has been/is filed, see below.

How? Either by cancelling one or more entire claims, by adding one or more new claims or by amending the text of one or more of the claims as filed.

A replacement sheet must be submitted for each sheet of the claims which, on account of an amendment or amendments, differs from the sheet originally filed.

All the claims appearing on a replacement sheet must be numbered in Arabic numerals. Where a claim is cancelled, no renumbering of the other claims is required. In all cases where claims are renumbered, they must be renumbered consecutively (Administrative Instructions, Section 205(b)).

The amendments must be made in the language in which the international application is to be published.

What documents must/may accompany the amendments?

Letter (Section 205(b)):

The amendments must be submitted with a letter.

The letter will not be published with the international application and the amended claims. It should not be confused with the "Statement under Article 19(1)" (see below, under "Statement under Article 19(1)").

The letter must be in English or French, at the choice of the applicant. However, if the language of the international application is English, the letter must be in English; if the language of the international application is French, the letter must be in French.

NOTES TO FORM PCT/ISA/220 (continued)

The letter must indicate the differences between the claims as filed and the claims as amended. It must, in particular, indicate, in connection with each claim appearing in the international application (it being understood that identical indications concerning several claims may be grouped), whether

(i) the claim is unchanged;
(ii) the claim is cancelled;
(iii) the claim is new;
(iv) the claim replaces one or more claims as filed;
(v) the claim is the result of the division of a claim as filed.

The following examples illustrate the manner in which amendments must be explained in the accompanying letter:

1. [Where originally there were 48 claims and after amendment of some claims there are 51]:
"Claims 1 to 29, 31 32, 34, 35, 37 to 48 replaced by amended claims bearing the same numbers; claims 30, 33 and 36 unchanged; new claims 49 to 51 added."

2. [Where originally there were 15 claims and after amendment of all claims there are 11]:
"Claims 1 to 15 replaced by amended claims 1 to 11."

3. [Where originally there were 14 claims and the amendments consist in cancelling some claims and in adding new claims]:
"Claims 1 to 6 and 14 unchanged; claims 7 to 13 cancelled; new claims 15, 16 and 17 added." or
"Claims 7 to 13 cancelled; new claims 15, 16 and 17 added; all other claims unchanged."

4. [Where various kinds of amendments are made]:
"Claims 1-10 unchanged; claims 11 to 13, 18 and 19 cancelled; claims 14, 15 and 16 replaced by amended claim 14; claim 17 subdivided into amended claims 15, 16 and 17; new claims 20 and 21 added."

"Statement under Article 19(1)" (Rule 46.4)

The amendments may be accompanied by a statement explaining the amendments and indicating any impact that such amendments might have on the description and the drawings (which cannot be amended under Article 19(1)).

The statement will be published with the international application and the amended claims.

It must be in the language in which the international application is to be published.

It must be brief, not exceeding 500 words if in English or if translated into English.

It should not be confused with and does not replace the letter indicating the differences between the claims as filed and as amended. It must be filed on a separate sheet and must be identified as such by a heading, preferably by using the words "Statement under Article 19(1)."

It may not contain any disparaging comments on the international search report or the relevance of citations contained in that report. Reference to citations, relevant to a given claim, contained in the international search report may be made only in connection with an amendment of that claim.

Consequences if a demand for international preliminary examination has already been filed

If, at the time of filing any amendments and any accompanying statement, under Article 19, a demand for international preliminary examination has already been submitted, the applicant must preferably, at the time of filing the amendments (and any statement) with the International Bureau, also file with the International Preliminary Examining Authority a copy of such amendments (and of any statement) and, where required, a translation of such amendments for the procedure before that Authority (see Rules 55.3(a) and 62.2, first sentence). For further information, see the Notes to the demand form (PCT/IPEA/401).

Consequence with regard to translation of the international application for entry into the national phase

The applicant's attention is drawn to the fact that, upon entry into the national phase, a translation of the claims as amended under Article 19 may have to be furnished to the designated/elected Offices, instead of, or in addition to, the translation of the claims as filed.

For further details on the requirements of each designated/elected Office, see the *PCT Applicants Guide*, Volume II.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	FOR FURTHER ACTION	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
15646		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/AU00/00838	13 July 2000	13 July 1999

Applicant COCHLEAR LIMITED et al

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 3 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing:

☐ contained in the international application in written form.

☐ filed together with the international application in computer readable form.

☐ furnished subsequently to this Authority in written form.

☐ furnished subsequently to this Authority in computer readable form.

☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. ☐ **Certain claims were found unsearchable** (See Box I).

3. ☐ **Unity of invention is lacking** (See Box II).

4. With regard to the **title**,

☒ the text is approved as submitted by the applicant.

☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

☒ the text is approved as submitted by the applicant

☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the drawings to be published with the abstract is Figure No. 2

☒ as suggested by the applicant.

☐ because the applicant failed to suggest a figure

☐ because this figure better characterizes the invention

☐ None of the figures

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU00/00838

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: A61F 11/04, H04R 25/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC A61F, H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPAT: cochlear, implant, hearing aid, signal processing, period, time interval, amplitude, magnitude, estimation

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5800475 A (Jules) 1 September 1998 The whole document	1-16
A	US 5749912 A (Zhang et al.) 12 May 1998 The whole document	1-16
A	US 4400590 A (Michelson) 23 August 1983 The whole document	1-16

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 August 2000	

Name and mailing address of the ISA/AU	Authorized officer
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	J. LAW Telephone No : (02) 6283 2179

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU00/00838

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	5800475	AU	54531/96	EP	745363	FR	2734711
		JP	8322873				
US	5749912	AU	38899/95	US	5549658	WO	9612456
US	4400590	NONE					

END OF ANNEX

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

RECD 27 FEB 2001

Applicant's or agent's file reference P15646PCAU/PNF:MB	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416).
International Application No. PCT/AU00/00838	International Filing Date *(day/month/year)* 13 July 2000	Priority Date *(day/month/year)* 13 July 1999

International Patent Classification (IPC) or national classification and IPC

Int. Cl. [7] A61F 11/04, H04R 25/00

Applicant

COCHLEAR LIMITED et al

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 3 sheets, including this cover sheet.

☐ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of sheet(s).

3. This report contains indications relating to the following items:

I	☒	Basis of the report
II	☐	Priority
III	☐	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
IV	☐	Lack of unity of invention
V	☒	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
VI	☐	Certain documents cited
VII	☐	Certain defects in the international application
VIII	☐	Certain observations on the international application

Date of submission of the demand	Date of completion of the report
6 February 2001	15 February 2001
Name and mailing address of the IPEA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized Officer **J. Law** Telephone No. (02) 6283 2179

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/AU00/00838

I. Basis of the report

1. With regard to the **elements** of the international application:*

- [X] the international application as originally filed.
- [ ] the description, pages , as originally filed,
  pages , filed with the demand,
  pages , received on with the letter of
- [ ] the claims, pages , as originally filed,
  pages , as amended (together with any statement) under Article 19,
  pages , filed with the demand,
  pages , received on with the letter of
- [ ] the drawings, pages , as originally filed,
  pages , filed with the demand,
  pages , received on with the letter of
- [ ] the sequence listing part of the description:
  pages , as originally filed
  pages , filed with the demand
  pages , received on with the letter of

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
These elements were available or furnished to this Authority in the following language which is:

- [ ] the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).
- [ ] the language of publication of the international application (under Rule 48.3(b)).
- [ ] the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, was on the basis of the sequence listing:

- [ ] contained in the international application in written form.
- [ ] filed together with the international application in computer readable form.
- [ ] furnished subsequently to this Authority in written form.
- [ ] furnished subsequently to this Authority in computer readable form.
- [ ] The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- [ ] The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

4. [ ] The amendments have resulted in the cancellation of:
   - [ ] the description, pages
   - [ ] the claims, Nos.
   - [ ] the drawings, sheets/fig.

5. [ ] This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

* *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

** *Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report*

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims	**1-18**	**YES**
	Claims		**NO**
Inventive step (IS)	Claims	**1-18**	**YES**
	Claims		**NO**
Industrial applicability (IA)	Claims	**1-18**	**YES**
	Claims		**NO**

2. Citations and explanations (Rule 70.7)

Claims 1-18

The invention of the claims is a signal processing method for a cochlear implant prosthesis comprising: estimation of the periodicity of the electrical signals, which have been converted from an acoustic signal and filtered by bandpass filters; estimation of the amplitude of the filtered signals; selection of only one of the filtered signals, based on the amplitude estimations, for stimulation of an electrode in each stimulation period, which is based on the periodicity of the filtered signals.

No individual citation or combination of citations show selection of only one of the filtered signals for stimulation of an electrode in each stimulation period.

The closest art of:

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shows cyclical stimulation of the electrodes in an order determined by a time distribution of the energy of a sound signal in frequency bands.